Radar Wind Profilers
&
Radio Acoustic Sounding Systems

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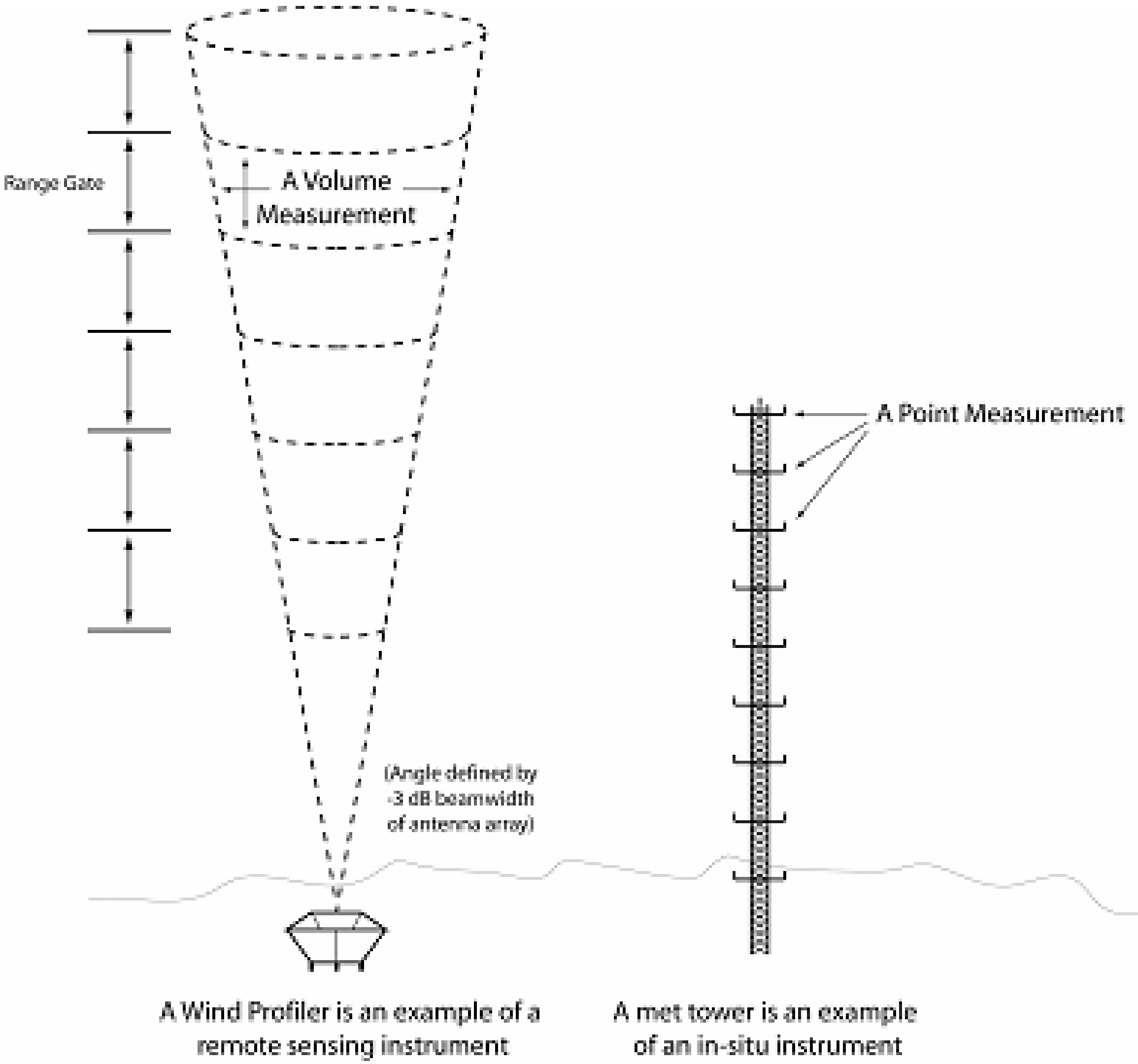
Outline

- History
- Theory
- Applications
- Summary

A Remote Sensing and an In-Situ Instrument



History

Radar Wind Profilers

History of Radar Wind Profiling

- *RA*dio *D*etection *A*nd *R*anging (*RADAR*) developed in the 1930s and fully exploited during WWII in the 1940s
- Doppler radar research began in the 1950s
- Ionospheric radar studies in 1950s revealed clear air effects in the troposphere
- Data processing explosion in the 1960s-70s allowed more comprehensive research and development
- Radio Acoustic Sounding Systems (RASS) as adjunct to radar wind profilers began experimentally in the 1970s
- Low frequency systems established for tropospheric wind profiling in the 1970s-80s
- NOAA established Colorado Wind Profiling Network in early 1980s in support of research and regional nowcasting/mesoscale forecasting activities
- NOAA established National Profiler Demonstration Network in the late 1980s-early 1990s
- Boundary wind profilers operating at higher frequencies were developed by NOAA in the late 1980s-early 1990s
- Mesonetworks of boundary layer systems established at Cape Canaveral, Vandenberg, Southern California, Europe, and Japan in late 1990s.

Theory

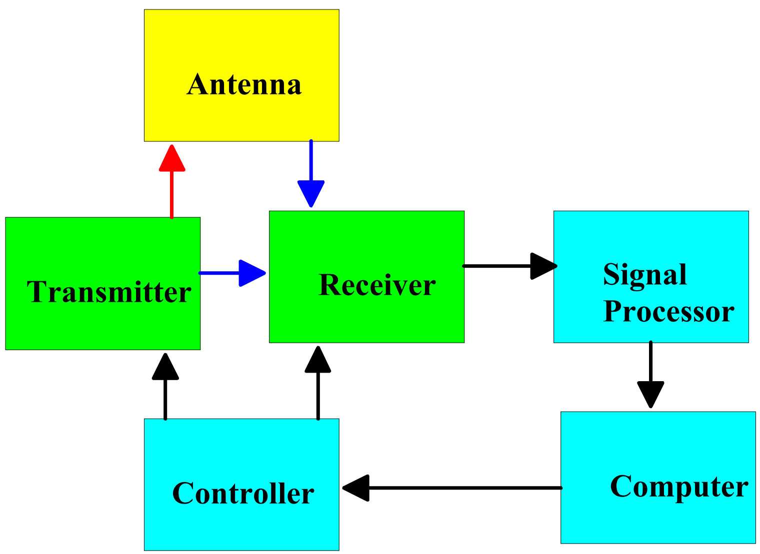
Radar Wind Profilers

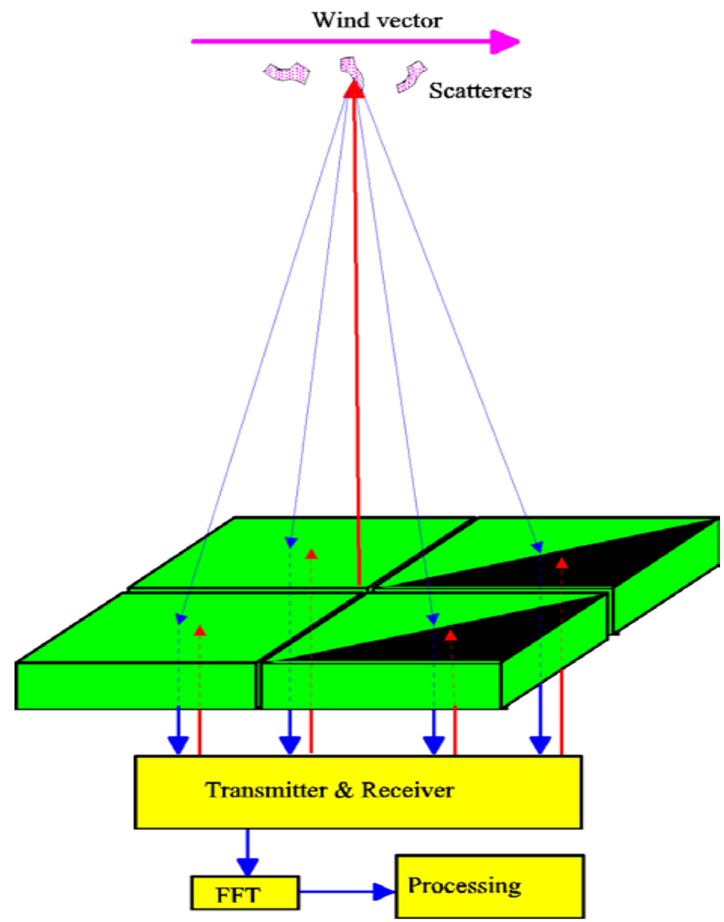
Basics.. Weather Radar/Wind Profiler

- RADAR (RAdio Detection And Ranging)
  - Conventional Weather Radar detects reflections from objects in the air (e.g. hydrometeors)
  - Scanning horizontally and “slicing” vertically a few degrees
- Wind Profiler RADAR
  - Measuring from ground UP, Clear Air RADAR
  - Reflection detected from turbulence and eddies
  - Wind Profilers operate below weather radar frequencies
  - Typical frequencies used in wind profiling
    - 45-65 MHz
    - 404-482 MHz
    - 915-924 MHz
    - 1280-1357.5 MHz

Wind Profiler System

Functional blocks in WP system

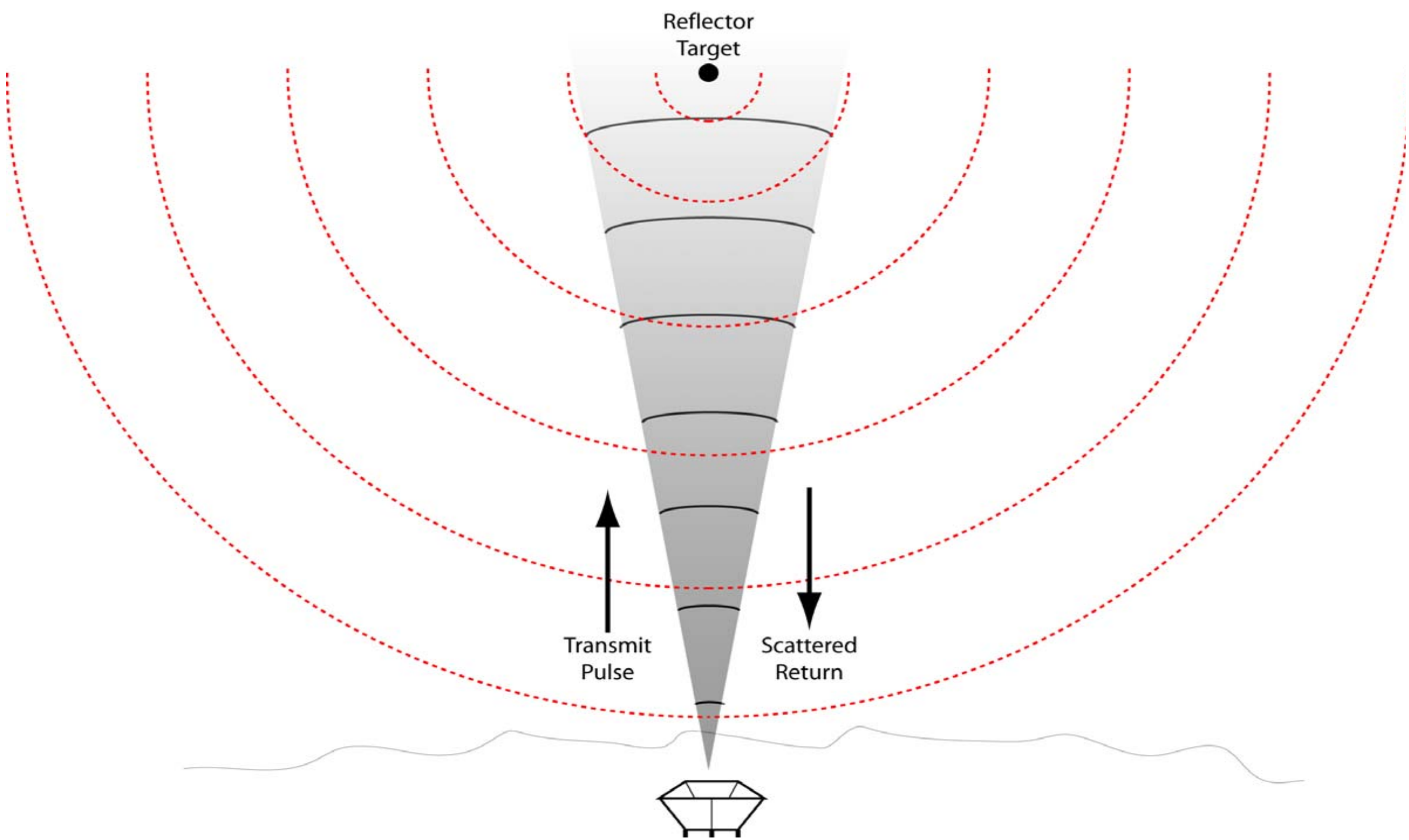




Basics.. Remote Sensing

- Remote Sensing from the Ground UP
  - Either Acoustic or electromagnetic pulse or both is sent into the atmosphere
  - Detection of the signal backscattered from refractive index inhomogeneties in the atmosphere
  - In clear air the scattering targets are the temperature and humidity fluctuations produced by turbulent eddies
  - Scale is about half of the wavelength for the transmitted radiation (the Bragg Condition)
  - The wavelengths of the acoustic (SODAR) and electromagnetic (WIND PROFILER) instruments are 0.07 to 0.18m or 0.24m --> thus sensitive to similar parts of the turbulent spectrum

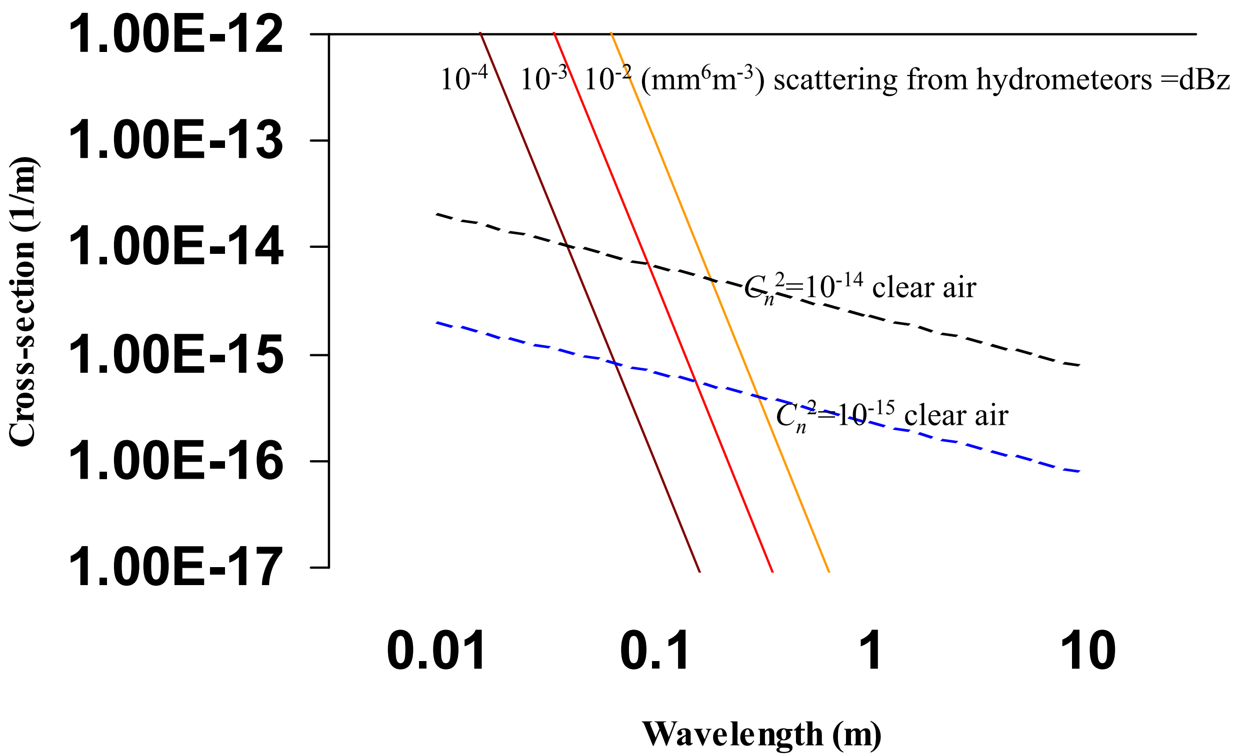
Wind Profiler RADAR Backscatter



Comparison of reflectivity

Reflectivity of scattering types:

- **for perturbance in n, wavelength dependence $\lambda^{-1/3}$**
- **backscatter from hydrometeors, dependency λ^{-4}**



Types of Radar scattering

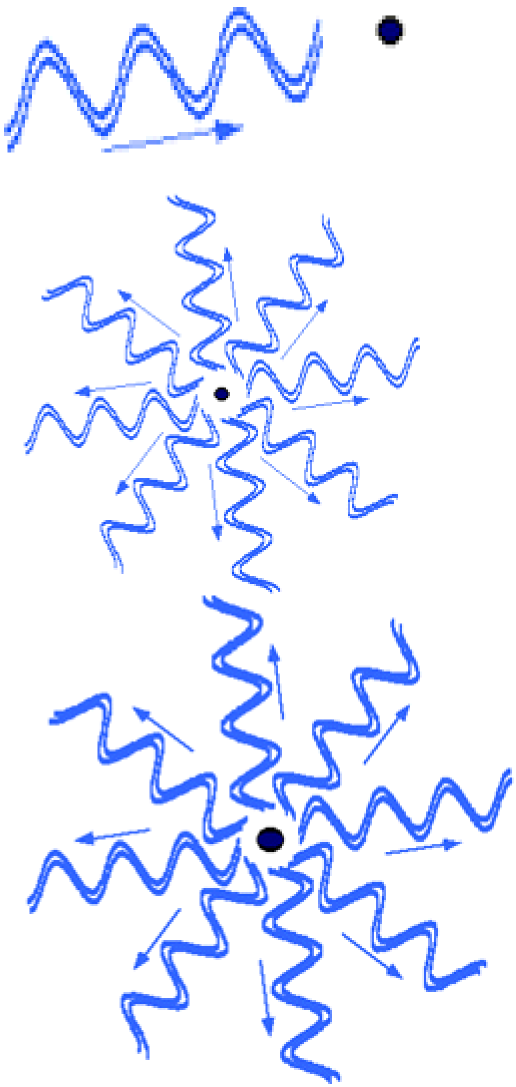
When a pulse encounters a target...

It is scattered in all directions.

Of interest is the signal component received back at the radar.

This signal is typically much weaker than the original sent from the transmitter and is called the "return signal".

The larger the target, the stronger the scattered signal.

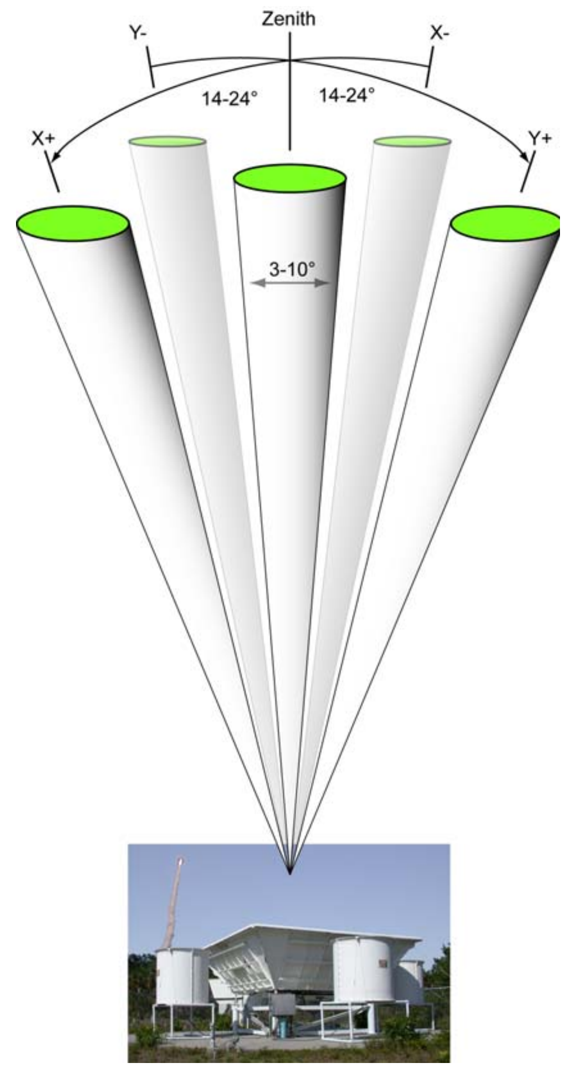


Types of Radar scattering

- Scattering from atmospheric targets:
  - irregularities in the index of refraction of the air
  - hydrometeors, particularly wet ones (rain, melting snow, water coated ice)
  - birds and insects (frequency dependant)
  - smoke plumes
- Multitude of targets may introduce serious errors
  - the measured velocity is that of rain, not wind
- Interfering signals:
  - ground and sea clutter
  - aircraft and migrating birds
  - RFI (depends on frequency band)

Doppler Beam Swinging (DBS)

- DBS method for wind vector calculations (u,v,w)
- radial scattered velocities measured with one vertical and 2 (4) off-zenith beams
- beam-pointing sequence is repeated every 1-5 minutes
- Electronic beam pointing with phase shifters using one antenna
- local horizontal uniformity of the wind field is assumed



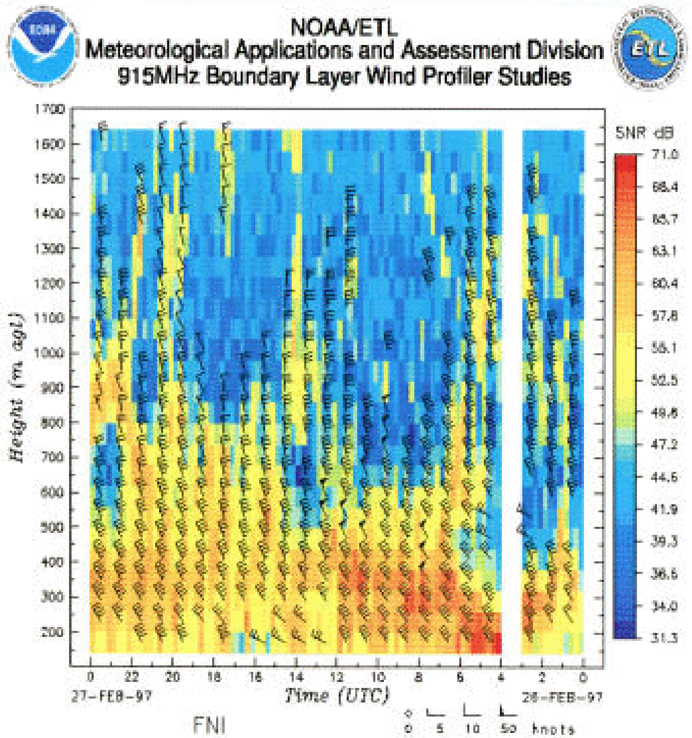
Fixed Beam DBS Antenna

Degreane 1 GHz profiler at Nice with cluttter fence

Photo courtesy of Degreane

Phased Array DBS Antenna (in support of NOAA Research)

Offshore Wind Profiling: Current Effort (ETL/NWS Collaboration for Coastal Forecasting)

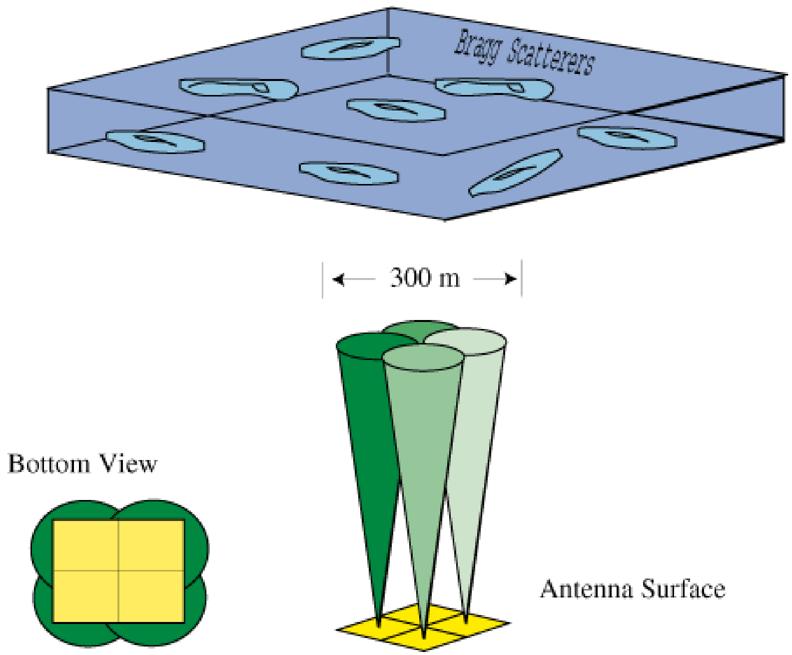


Farallon Islands

Photo Courtesy of NOAA/ETL

Spaced Antenna Architecture

Multiple Antenna Profiler (MAPR)



Assumes: homogeneous, stationary scatterers over **300 m** and **30 sec**

Measures: wind in inhomogeneous atmospheric conditions
large-scale turbulence intensity

Limited use in low SNR; sensitive to clutter

Courtesy of NCAR

Spaced Antenna

- **ATRAD, Australian company**
  - **50MHz Wind Profiler**
  - **Installed at Sydney for 2000 Olympics**

Photo courtesy of ATRAD

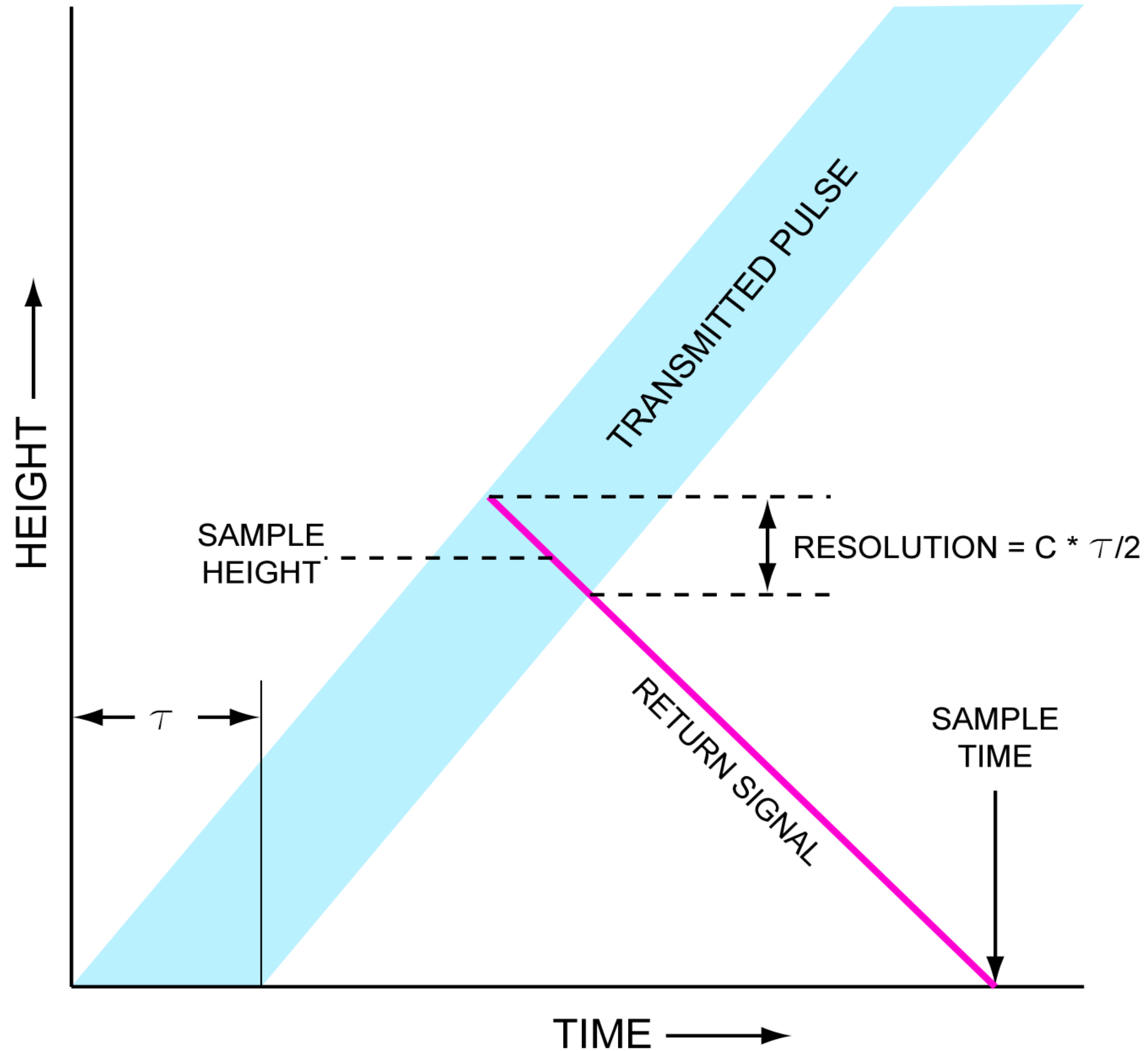
Doppler shift

- **Doppler Formula:**

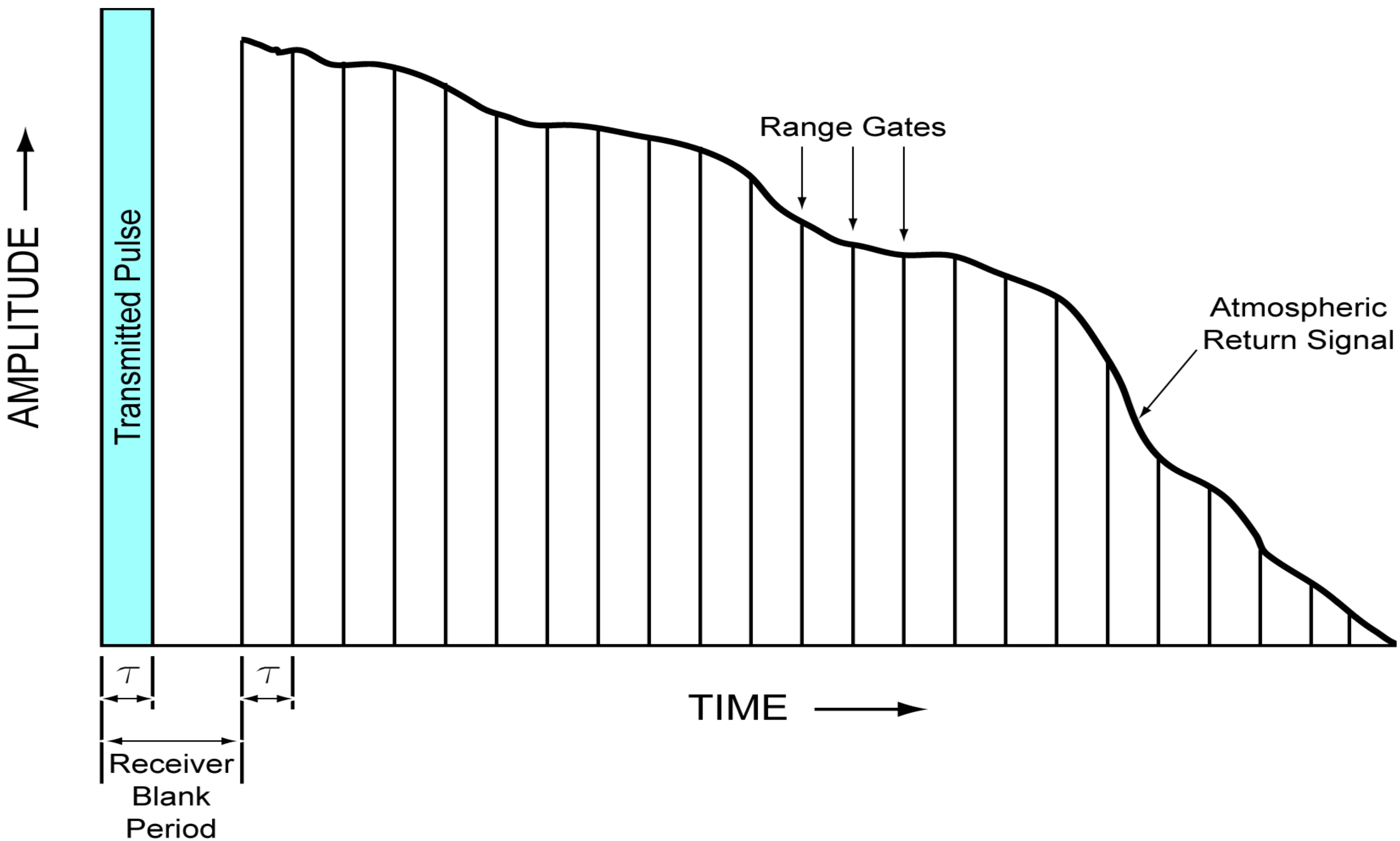
$$f_D = -\,{}^{2V_r}\!/_{\lambda}$$

- **Measurement of wind speed based on the Doppler shift in the received signal:**
    - **where Vr is the radial velocity of the scatterers**
- **Examples of Wind Profiler Doppler shift (radial velocity 10m/s)**
    - **50MHz, wavelength 6m, Doppler shift 3.34Hz**
    - **449MHz, wavelength 0.66815m, Doppler shift 29.9Hz**
    - **1290MHz, wavelength 0.23m, Doppler shift 86Hz**

Transmission pulse versus resolution



Range gates



AMPLITUDE
Transmited Pulse
Range Gates
Atmospheric Return Signal
τ
τ
Receiver Blank Period
TIME

Doppler peak display

N = Noise power

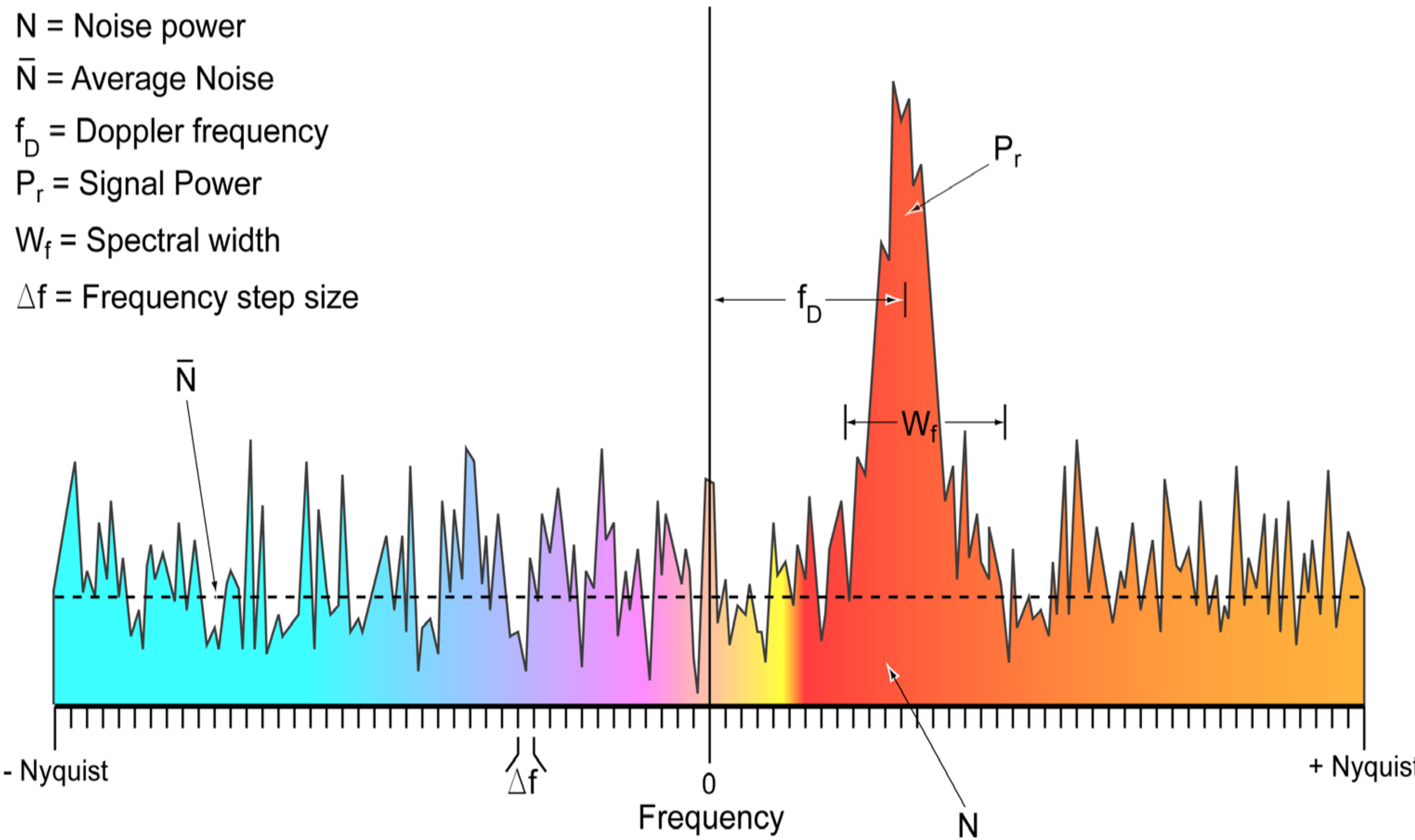
$\bar{N}$ = Average Noise

f_D = Doppler frequency

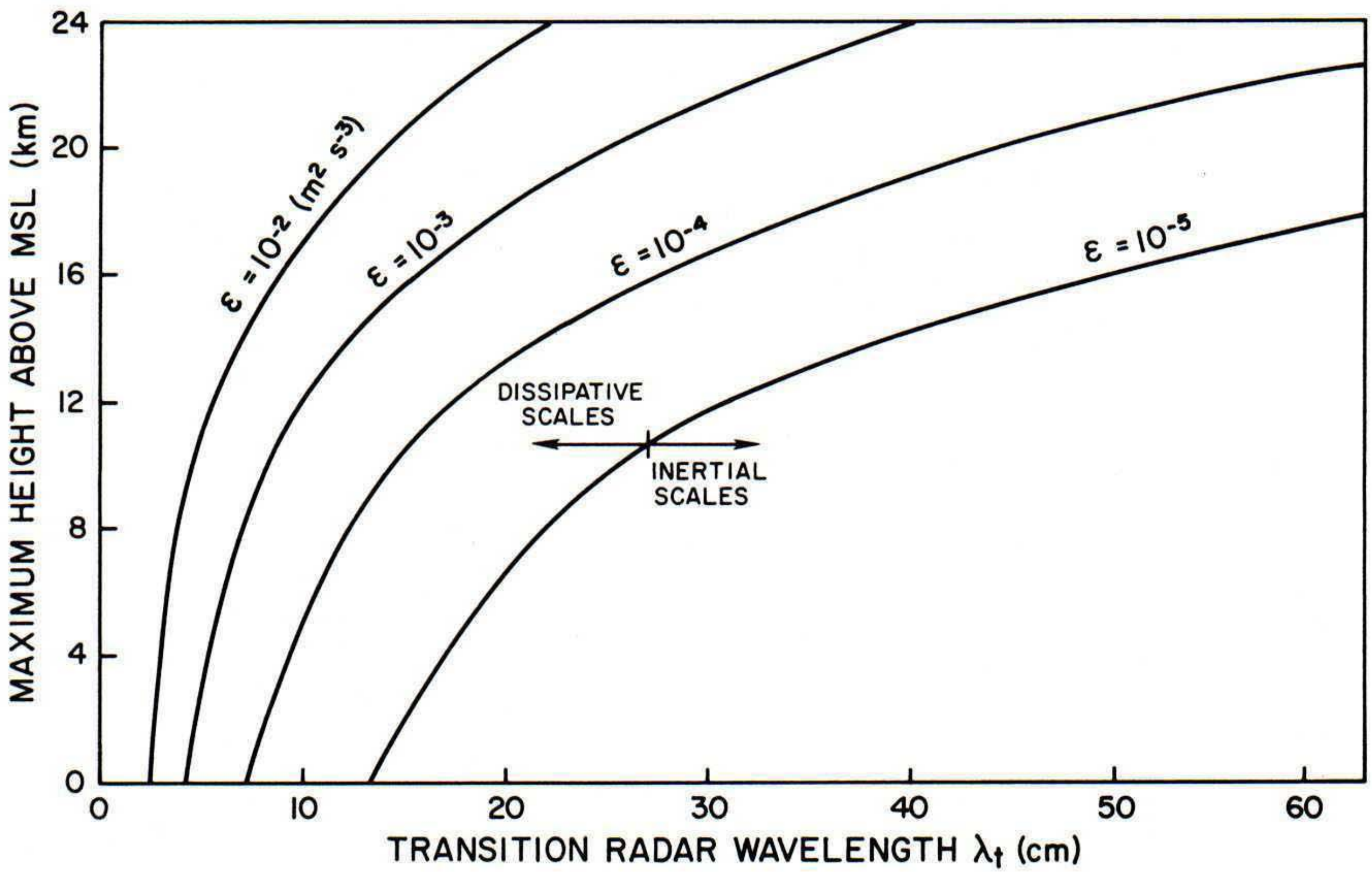
P_r = Signal Power

W_f = Spectral width

Δf = Frequency step size



Altitude of Radar Returns vs. Turbulence (↙)

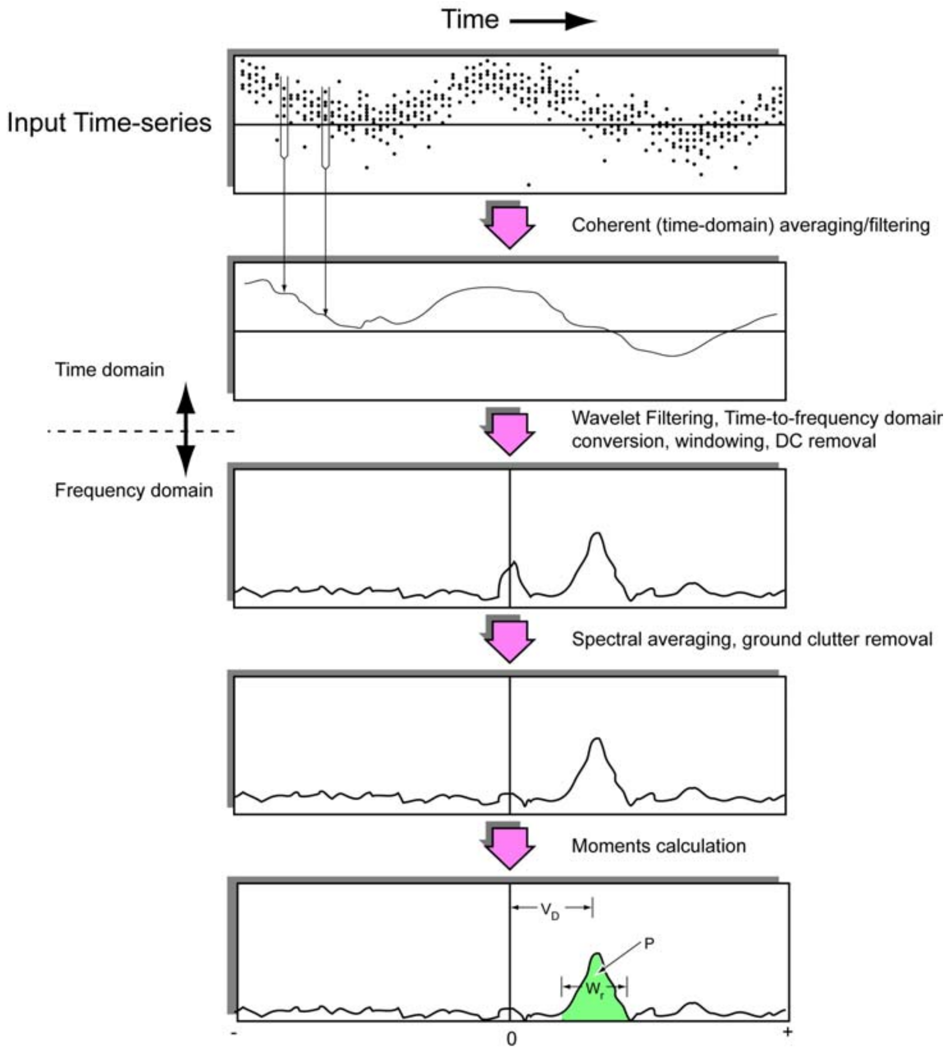


After *Doppler Radar and Weather Observations (1984), by* Doviak and Zrnic

Basics.. Remote Sensing

- Cloud droplets are small enough to give a measurable signal
- During Precipitation backscattered signal from raindrops may become comparable to the clear air contribution
- Backscattered signal is analyzed in the frequency domain to extract the relative power, the Doppler shift and width of the signal's spectral peak
- The Doppler shift gives the radial component of the wind velocity
- By using several antennas or electronic beam swinging the radial velocity of the three components (u, v, w) of wind vectors can be computed

Signal Processing Steps



Basics.. Bragg scattering

- **Wind Profiling Radar depend on the scattering of electromagnetic energy by minor irregularities in the index of refraction {Echoes come from refractive index gradient (Bragg scattering) }**
  - **Related to the speed at which electromagnetic energy propagates through the atmosphere**
  - **An electromagnetic wave encounters a refractive index irregularity**
    - **a minute amount of energy is scattered in all directions**
    - **result from turbulence**
  - **Backscattering toward point of origin occurs preferentially from irregularities of a size and on the order of one half the wavelength of the incident wave**

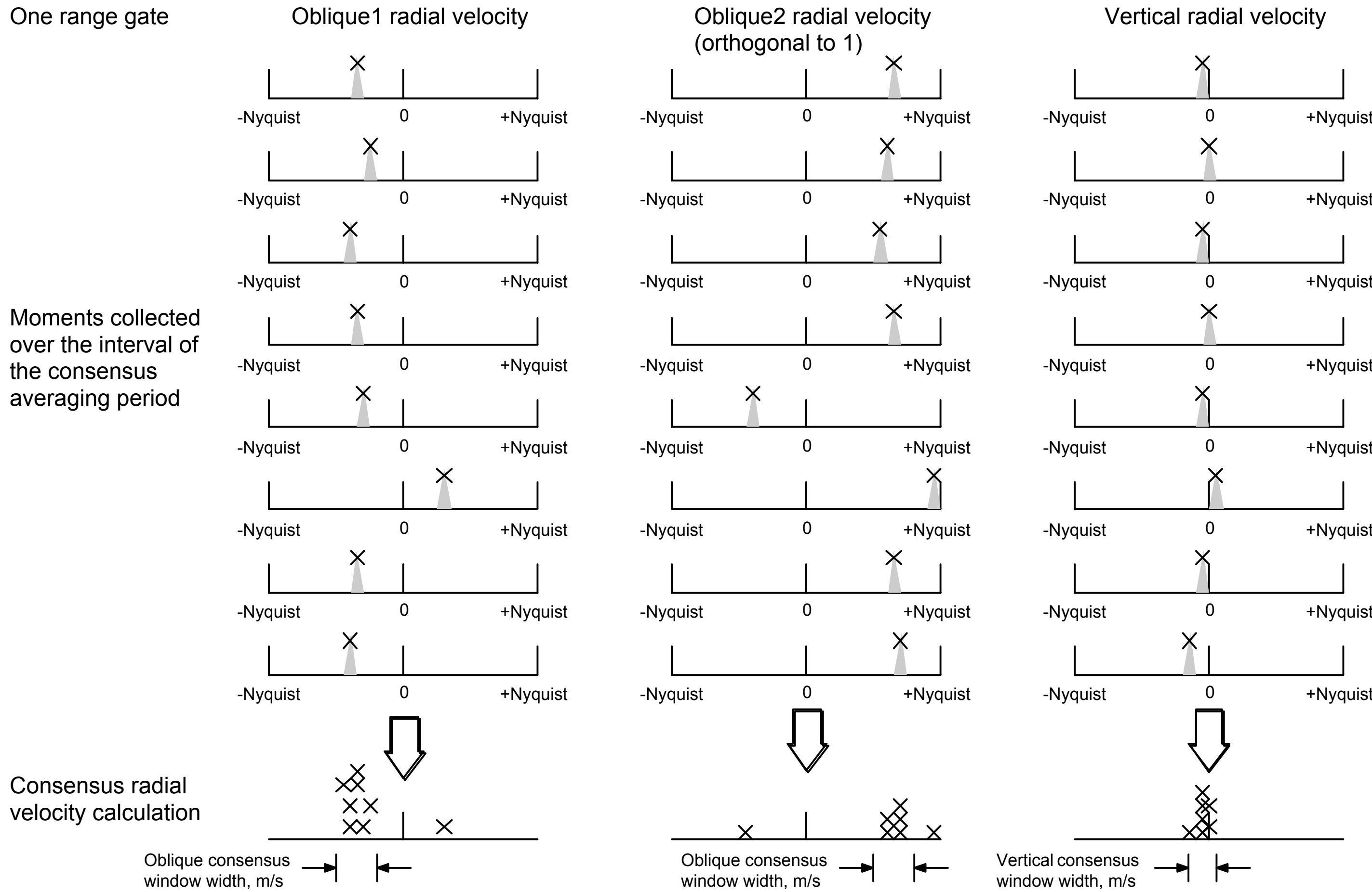
Basics ... cont.

- Refractive index fluctuations are carried out by the wind so they are used as tracers
- Irregularities exist in a size range of a few centimeters to many meters ---> Wind Profilers operate below weather radar frequencies
- Different methods of wind measurement used with numerous variations:
  - SA (Spaced Antenna)
  - DBS (Doppler Beam Swinging)
- Doppler shift in the backscattered signal is used to derive the wind speed and direction as function of height

Algorithms in brief..

- Consensus
  - Statistical approach to selecting average winds during sampling period
- Running Consensus
  - Continuous update replacing oldest data in the consensus period with most recent data
- Multi-Peak Picking
  - Selects atmospheric peak from multiple Doppler peaks in the spectra
- Fuzzy Logic
  - Applies fuzzy logic to selection of atmospheric peaks in specta
- Wavelet Transforms
  - Ground, aircraft and bird clutter removal by using the concept of discrete multi-resolution analysis and non-parametric estimation theory
- Weber-Wuertz
  - Automated Quality Control of winds based on predetermined criteria.
- C_n^2
  - Radar reflectivity is proportional to the structure constant C_n^2 of the turbulent refractivity index field

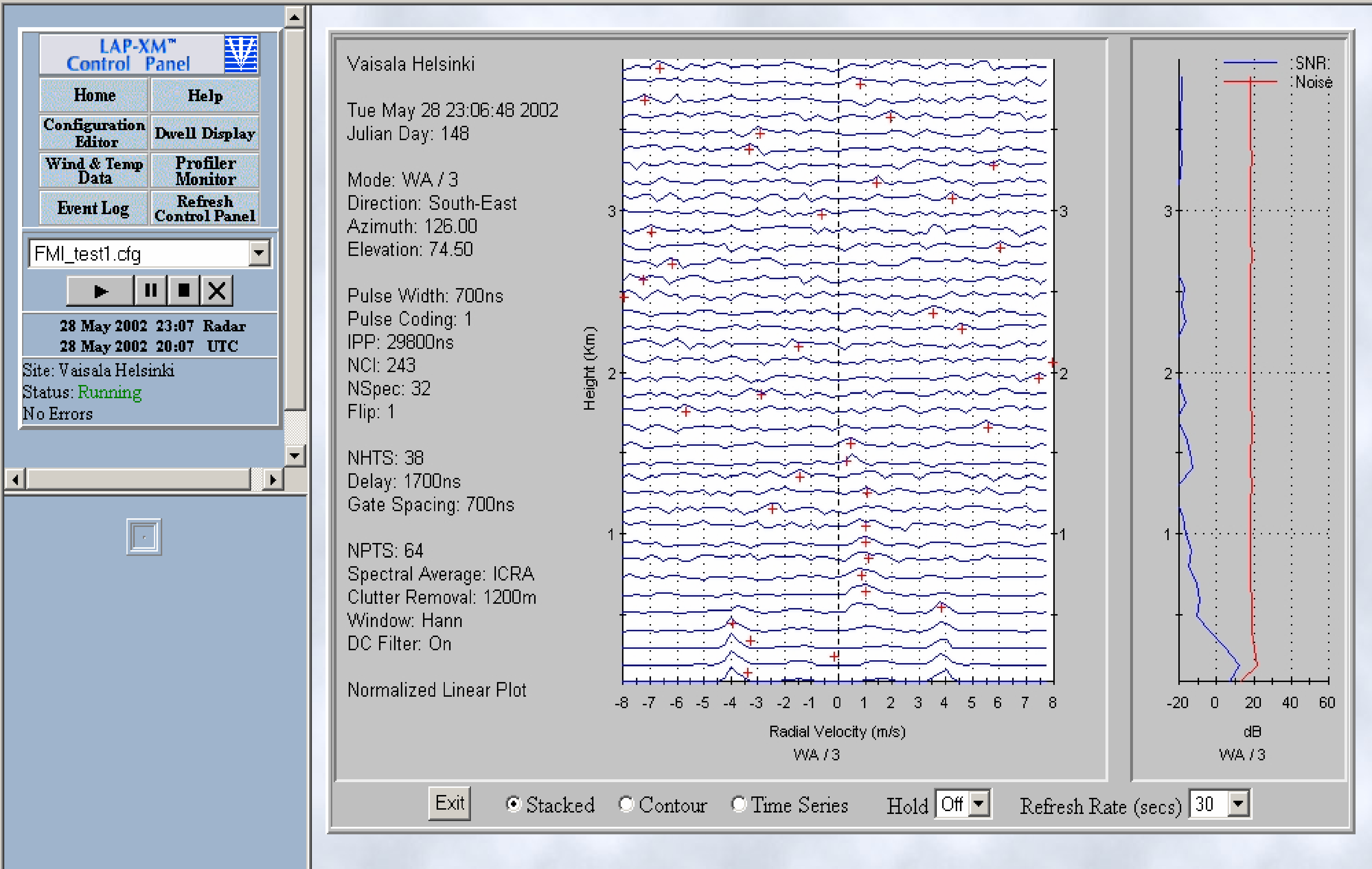
Consensus Algorithm Procedure



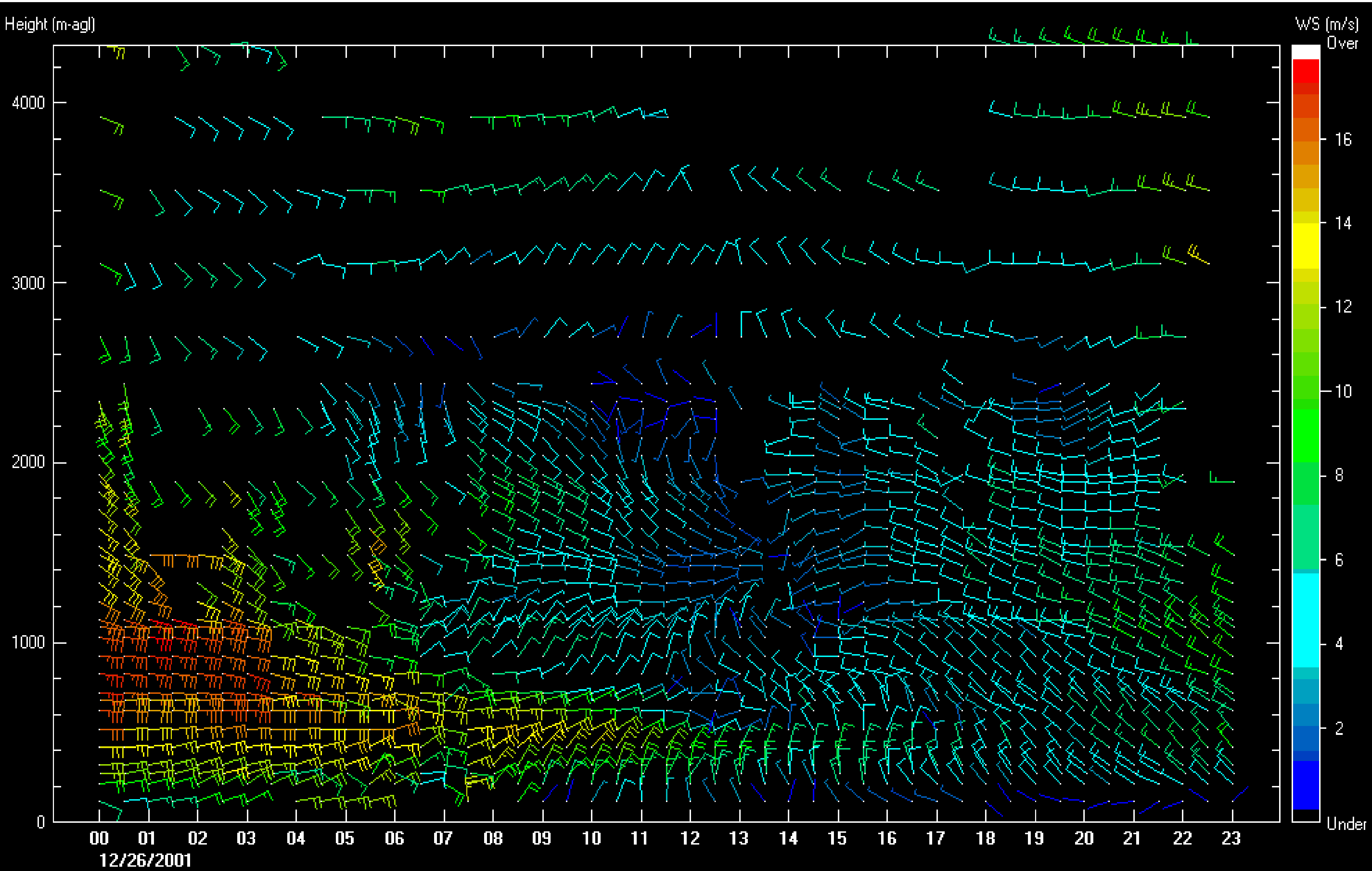
To be valid, the number of radial velocity samples within the window must exceed the consensus percentage.
If valid, the mean of the velocities within the window is the radial velocity of the consensus period.

If the all radial velocities are valid, then a wind speed and direction is calculated for the consensus period.

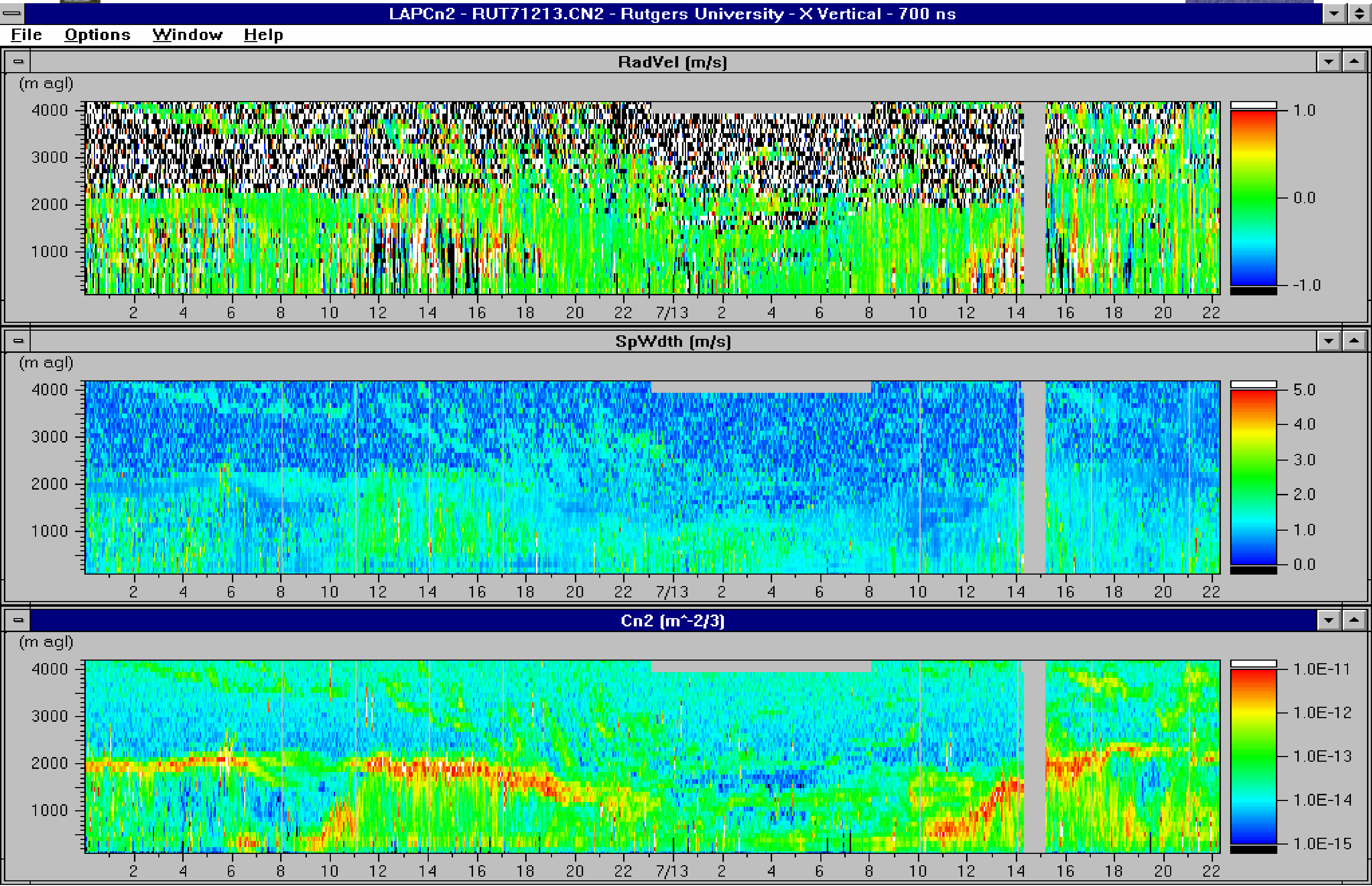
Stacked Spectral Data -- 1290 MHz



Time-Height Wind Barb Display



Moments data



Refractive irregularities

- **Refractive index *n* (or *N*) of air depends on pressure *p* [hPa], temperature *T* [K] and water vapor pressure *e* [hPa]:**

$$N = (n-1)\cdot 10^6 = 77.6\frac{p}{T} + 71.6\frac{e}{T} + 3.7\cdot 10^5\frac{e}{T^2}.$$

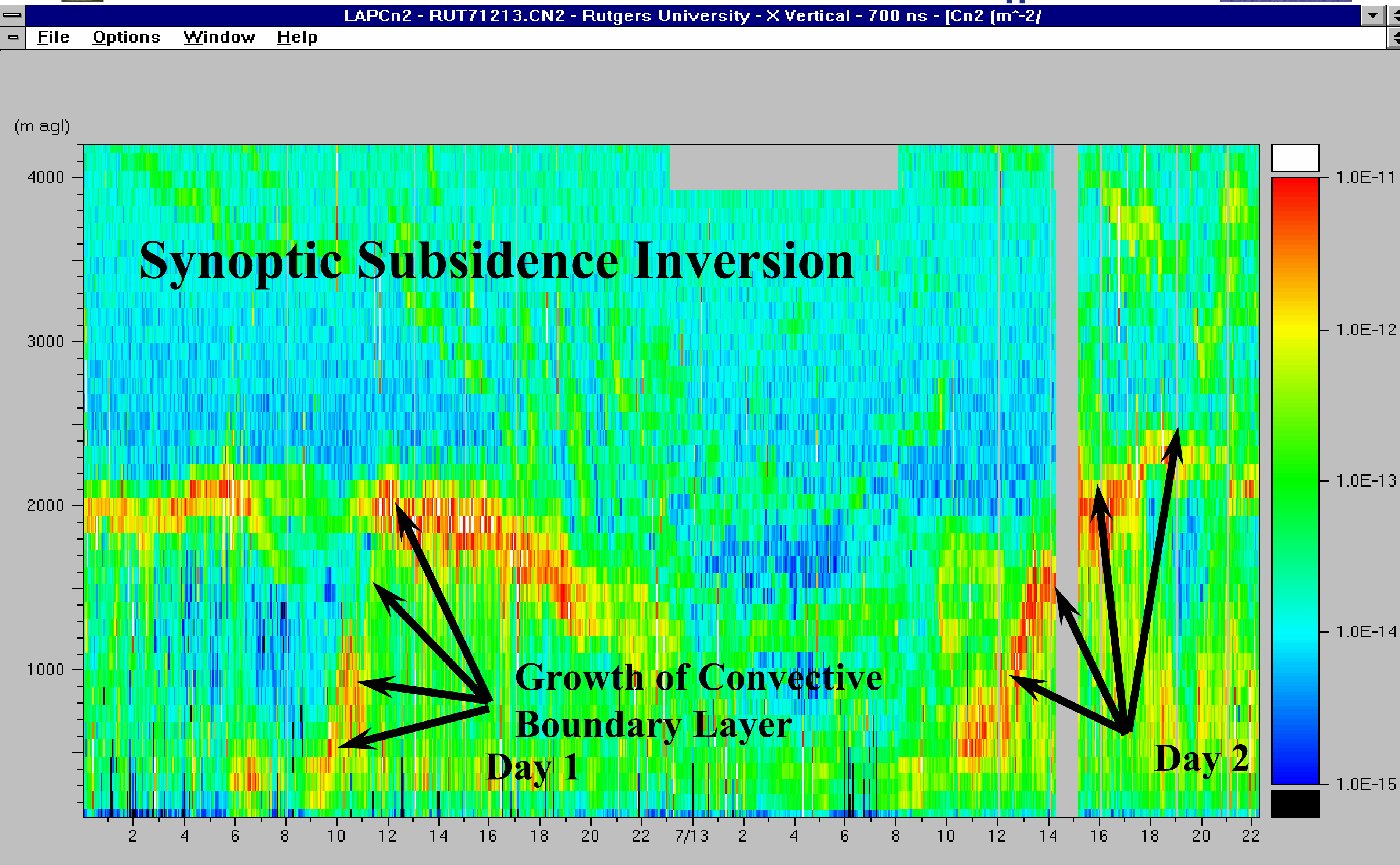
- **Important scale of perturbation is λ / 2 :**
  - **Reflected waves reinforce (in-phase reflected waves)**

- **Variation of *n* upon displacement (*r´*- *r*) :**

$$\left\langle \left[n(\bar{r}') - n(\bar{r})\right]^2 \right\rangle = C_n^{\,2}(\bar{r}' - \bar{r})^{2/3},$$

C_n^2 is the refractive index structure parameter

Boundary Layer Evolution (C_n^2 data)



RASS

- Radio Acoustic Sounding System (RASS)
  - Provides profiles of virtual temperature
  - Emits a strong continuos (5 minutes/hour) acoustic sine wave synchronized to RADAR frequency
    - Fe 1290MHz---->RASS output 2580Hz (half wavelength)
  - Tone burst travels as a compression wave with the speed of sound upwards in the atmosphere
  - Wind Profiler measures the speed of propagation of the sound burst
  - Since the speed of sound depends on the air temperature, virtual temperature can be computed from the received signal

RASS Example

Degreane 1 GHz profiler with RASS

Photo courtesy of Degreane

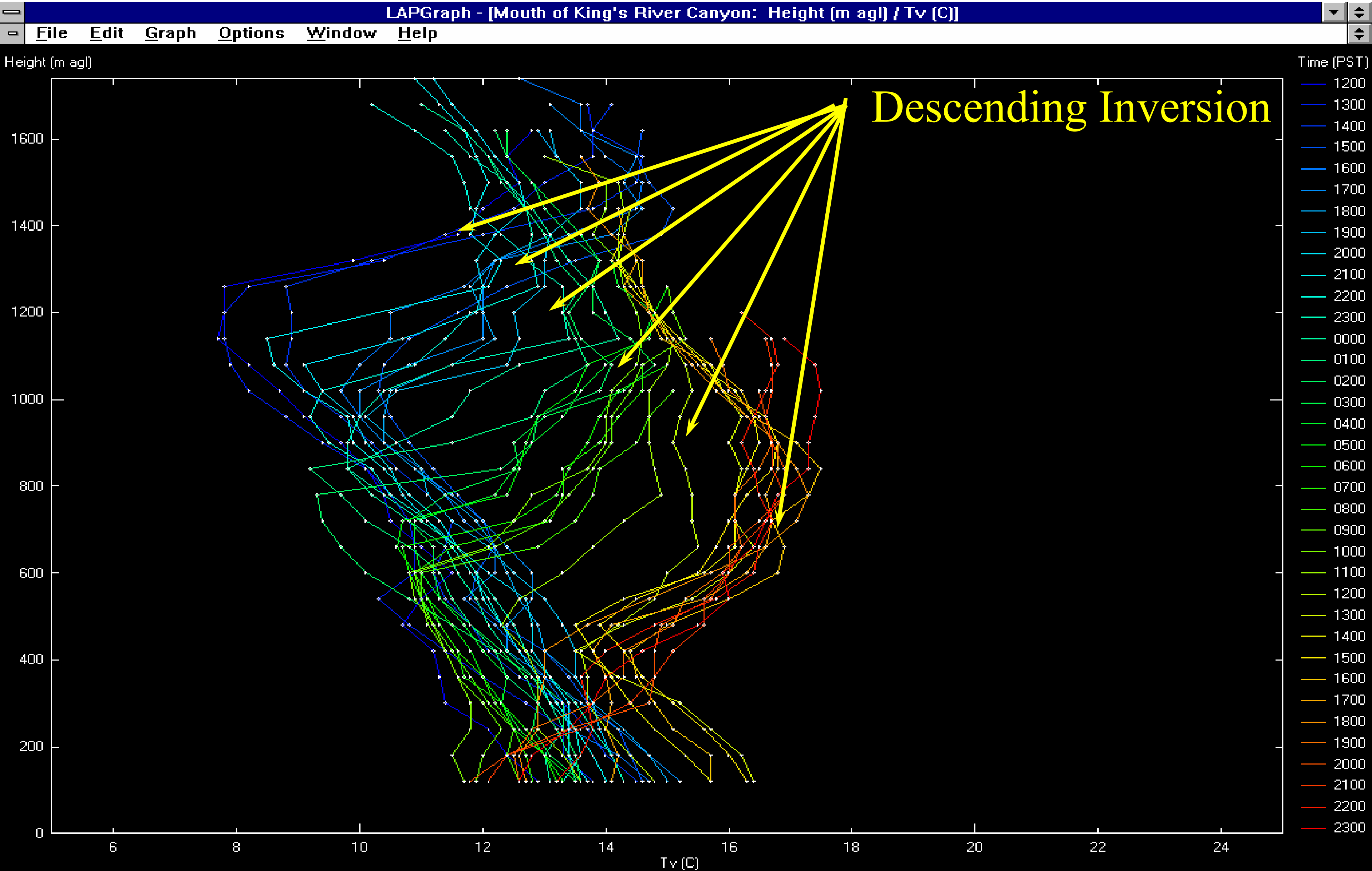
Boundary Layer WP w/RASS at Ontario Int'l Airport CA

Mobile Boundary Layer WP with Sodar as RASS

Tropospheric 400 MHz+ Profiler

Vandenberg AFB 449 MHz Profiler as part of US National Demonstration Network -- Uses Vaisala Electronics and LAP-XM software with Lockheed Martin Antenna and Transmitter (Currently installed at Plattville Colorado)

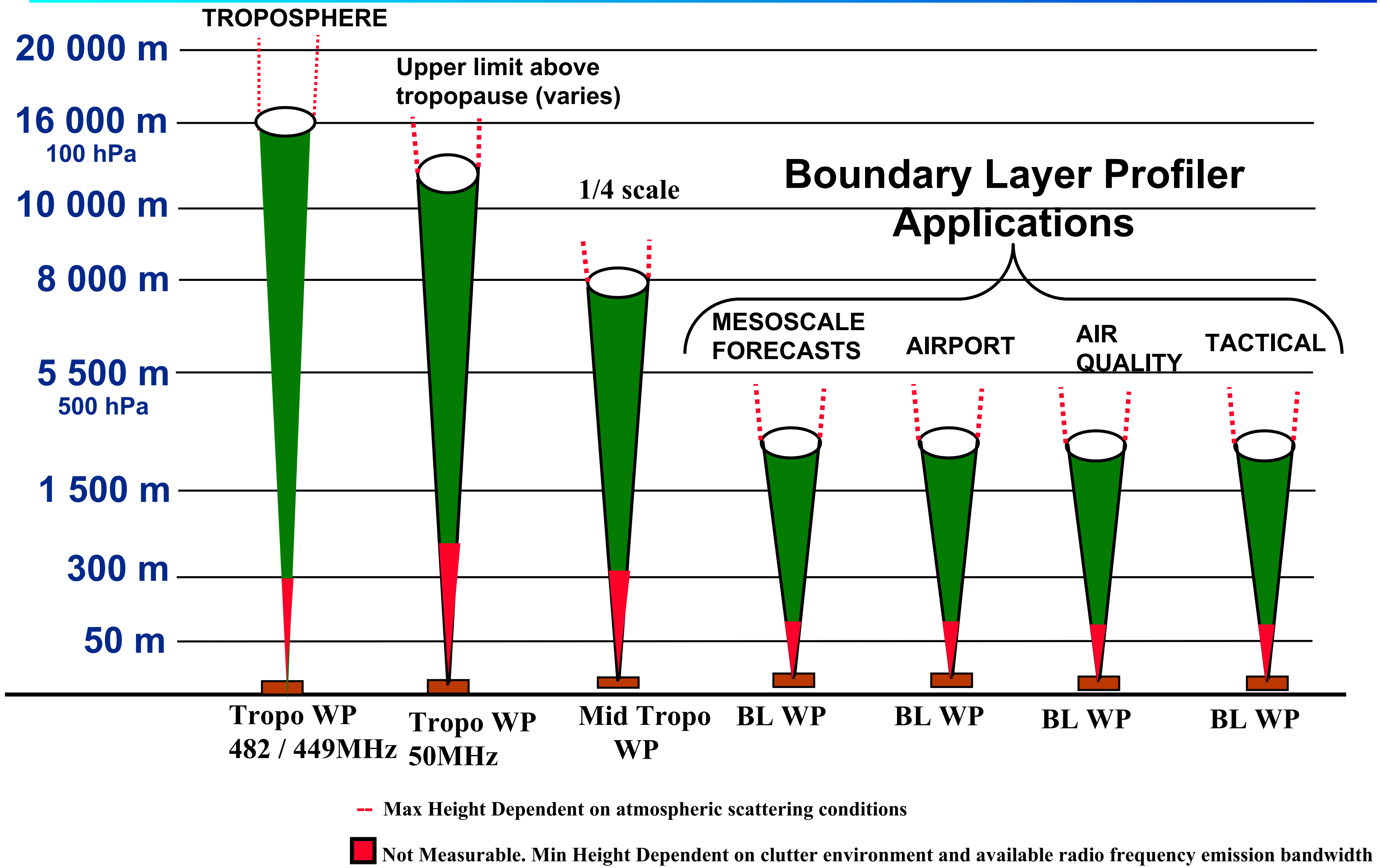
Descending Inversion



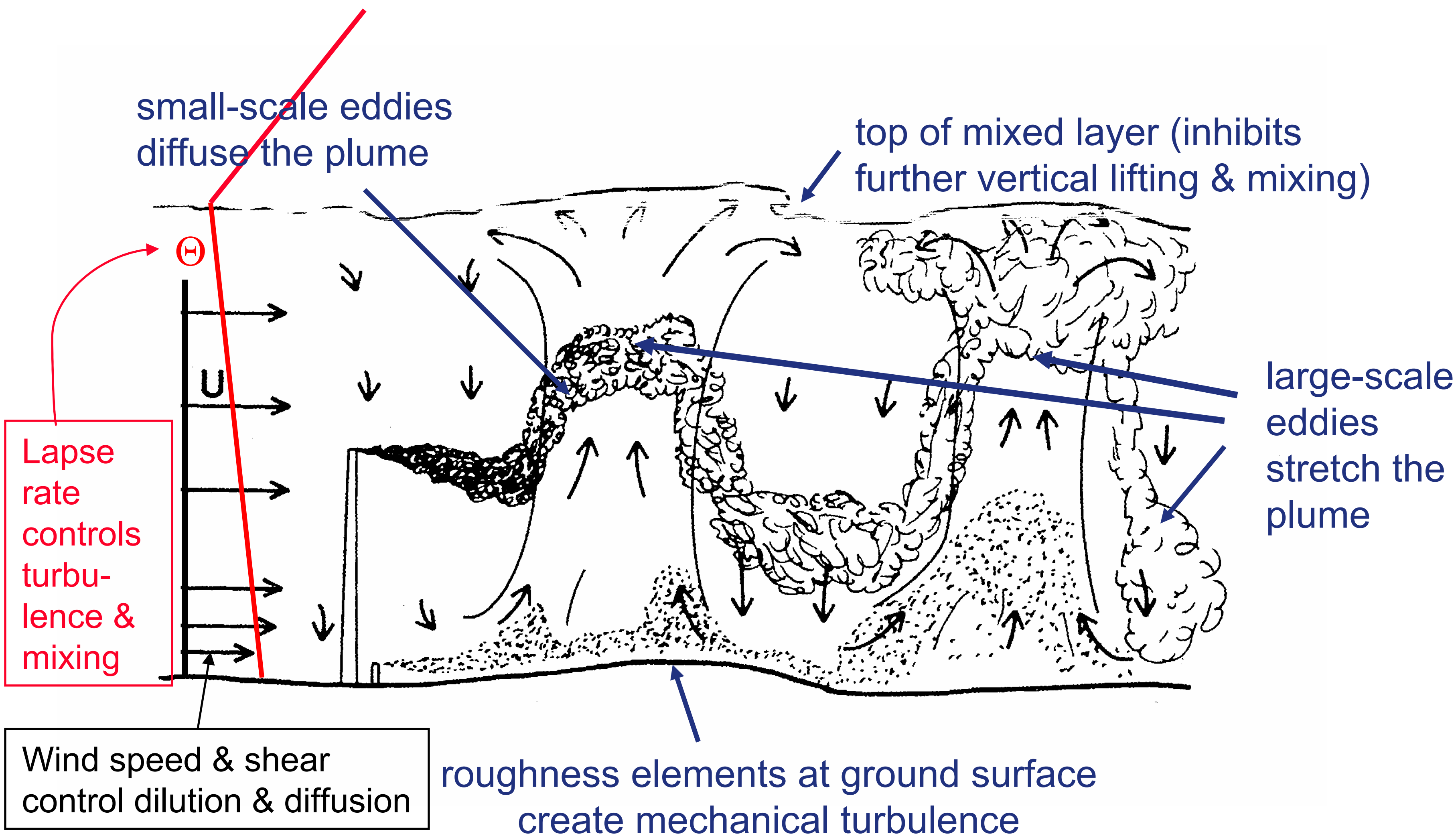
Applications

Radar Wind Profilers

Wind Profiler Applications

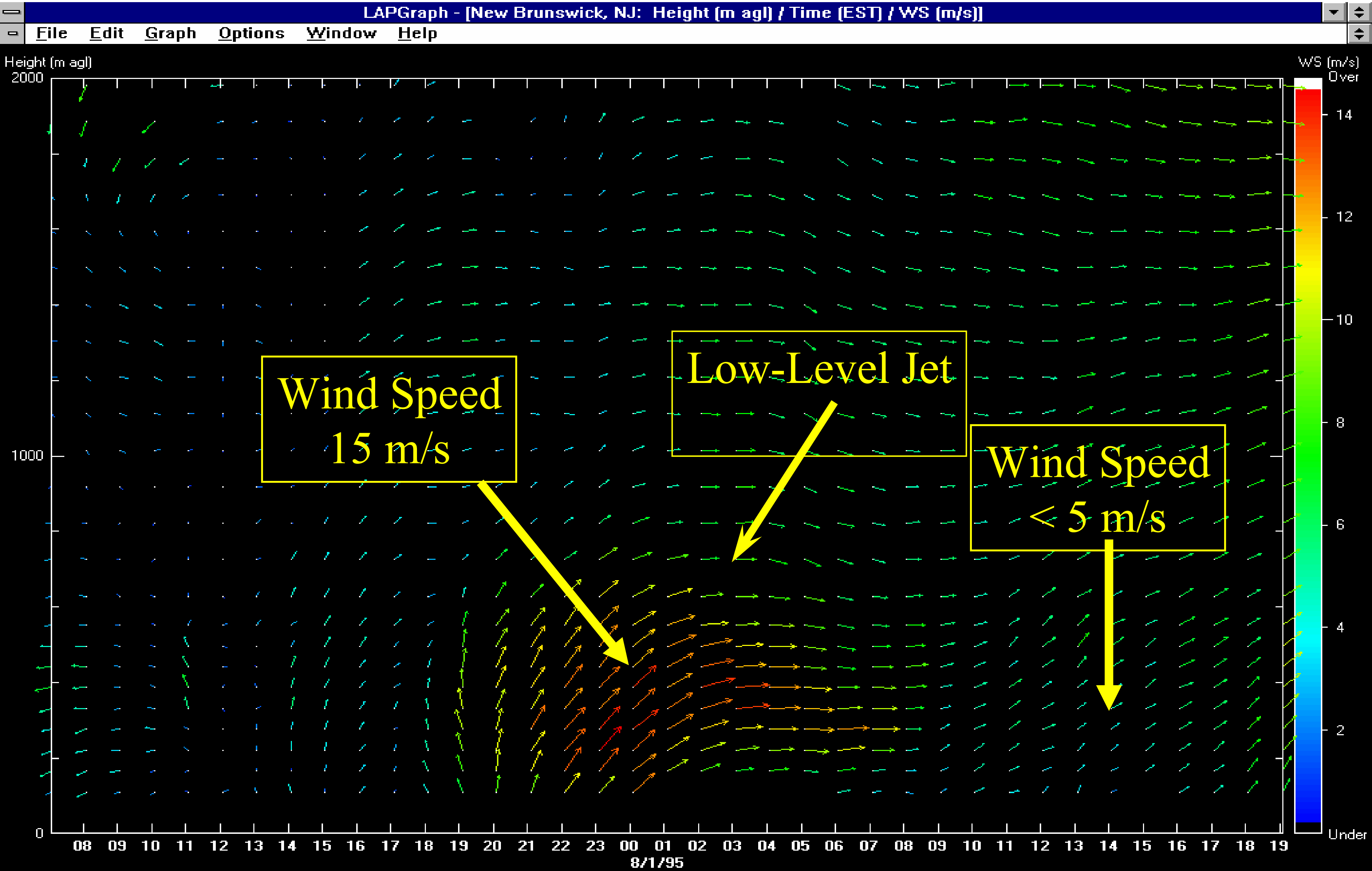


Some Aspects of Air Quality Meteorology



Boundary Layer WP w/RASS for Air Quality in Thailand

Nocturnal Low-Level Jet

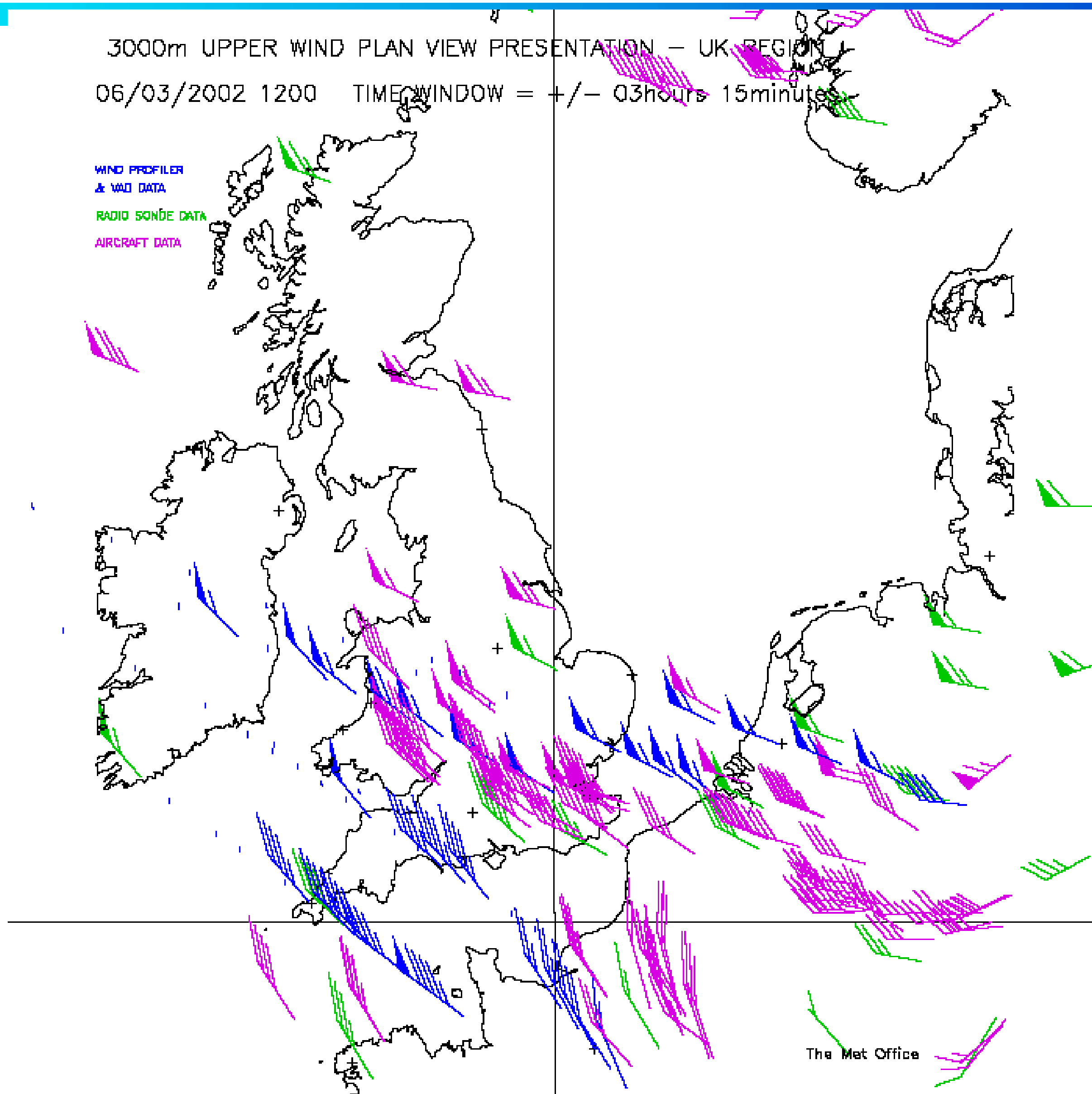


Vienna Airport 1280MHz

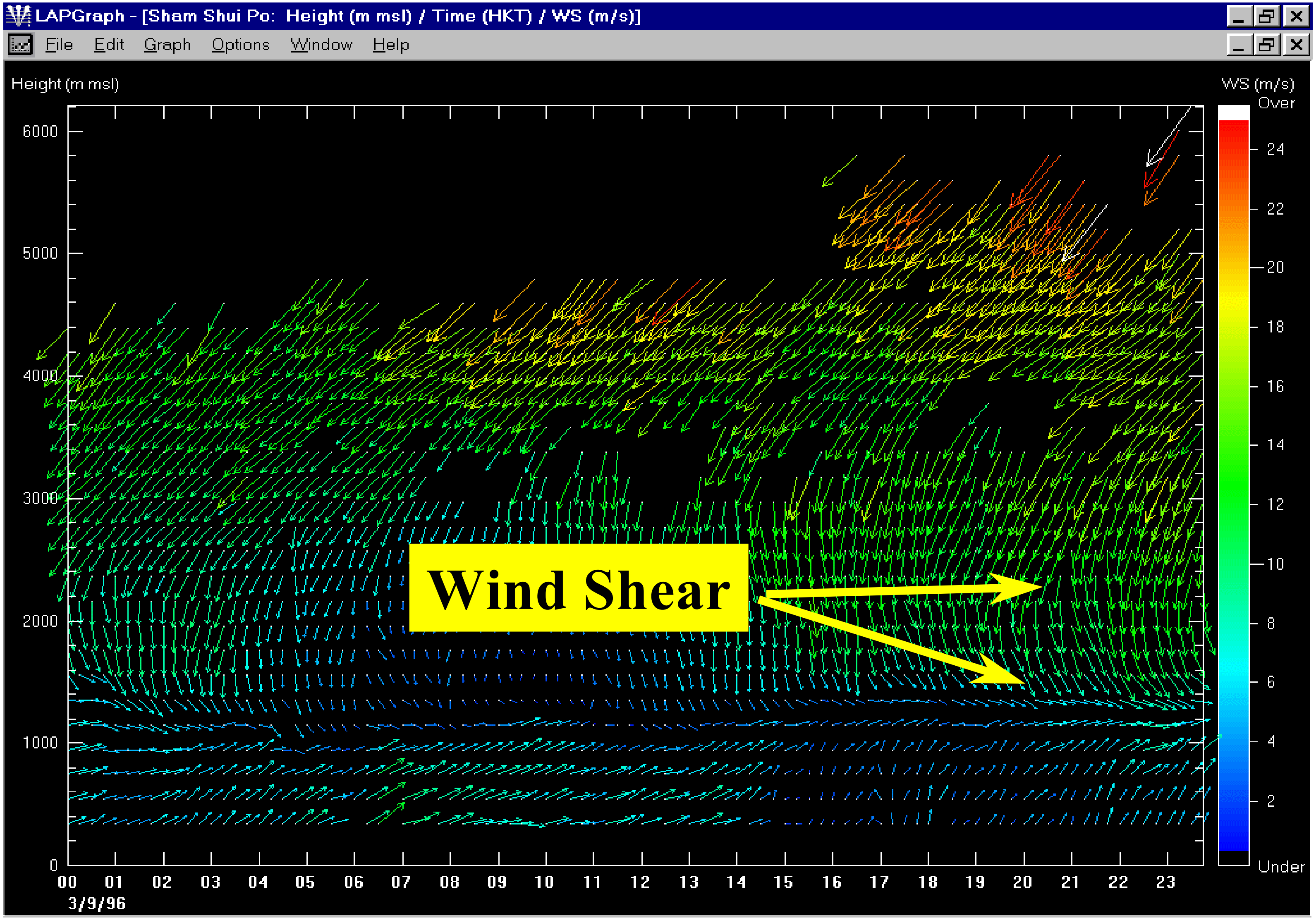
European Profiler Network

Courtesy of CWINDE

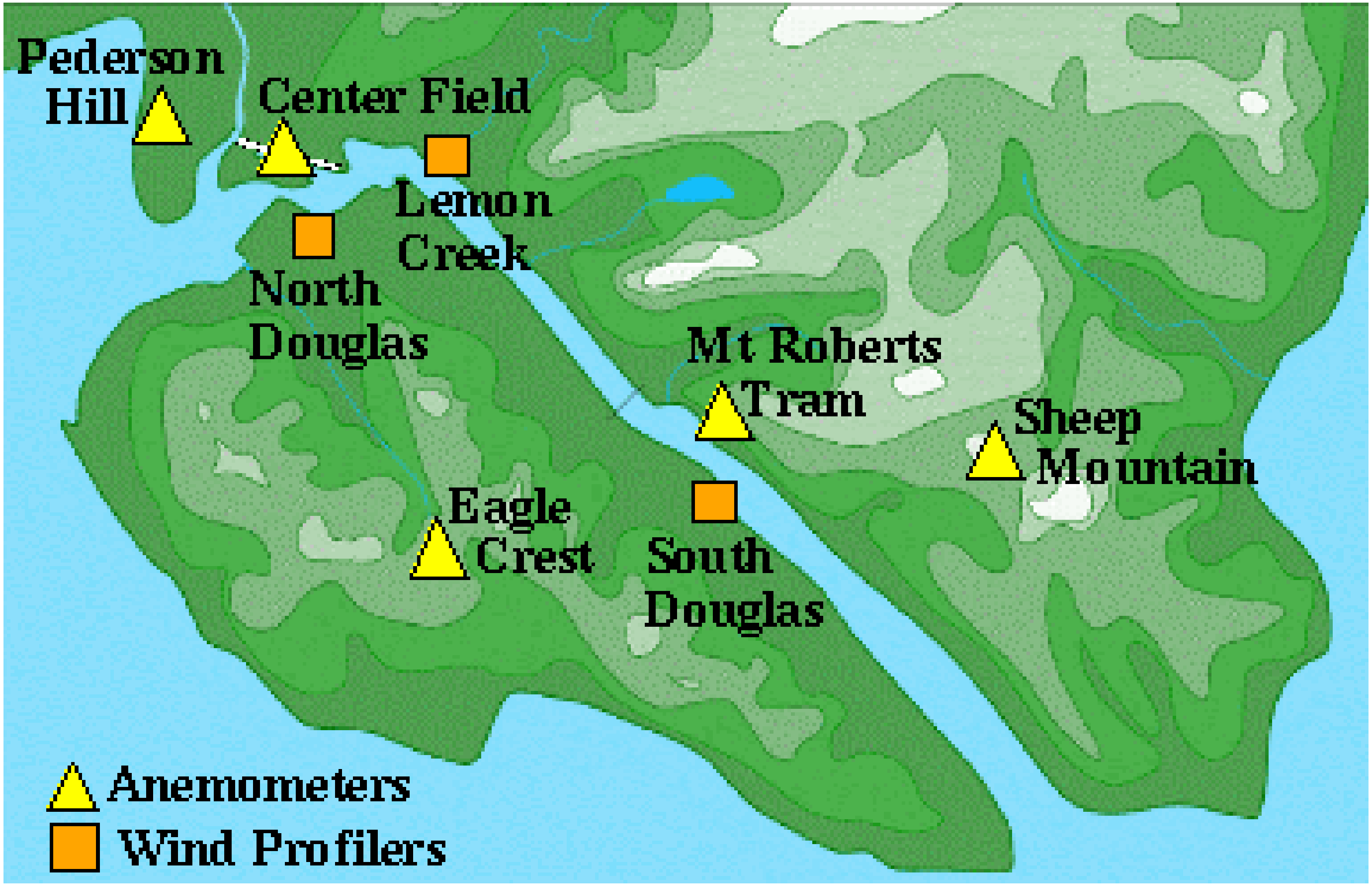
CWINDE Wind Plan View



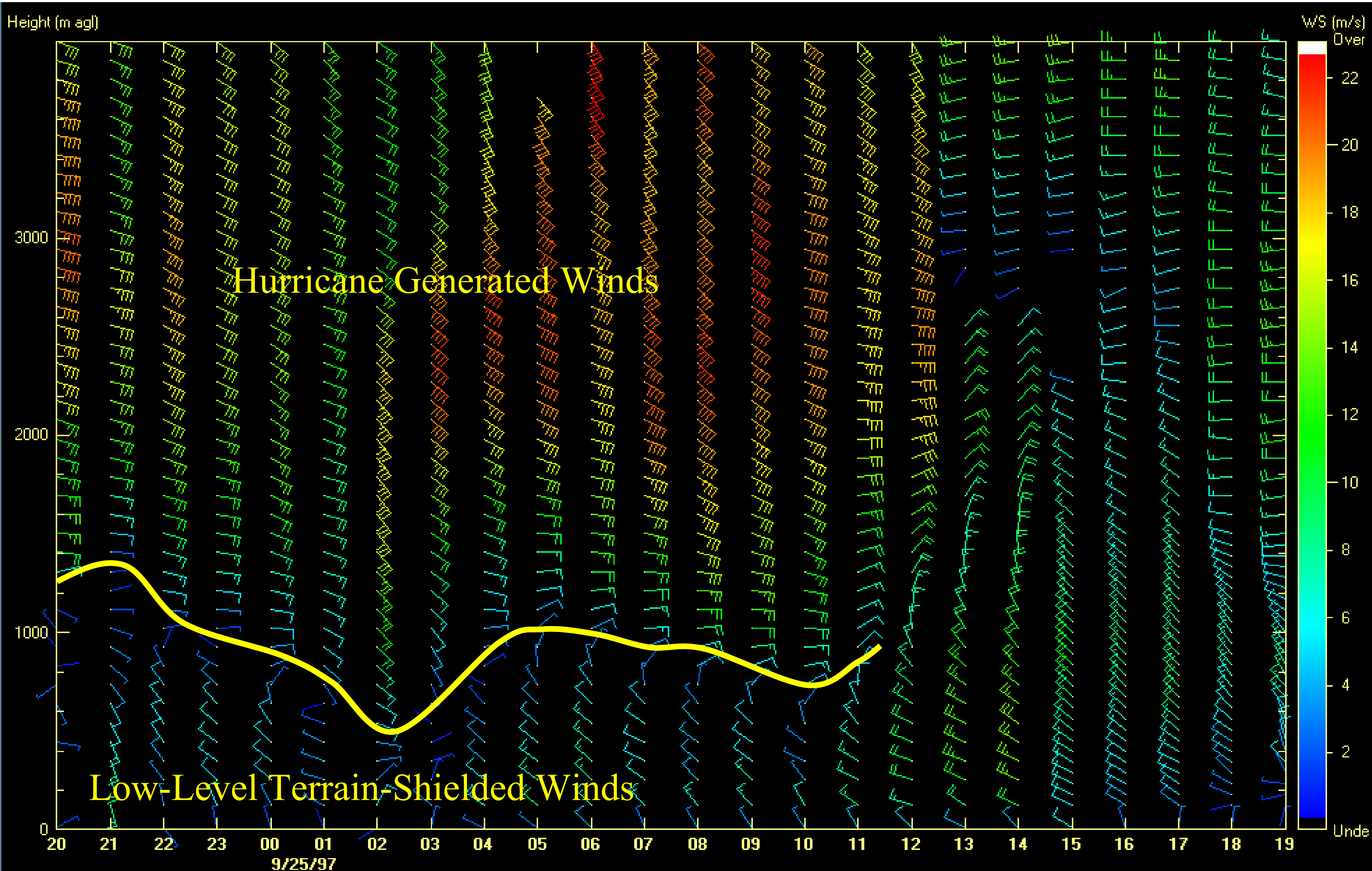
Wind shear depicted on radar wind profiler time-height series



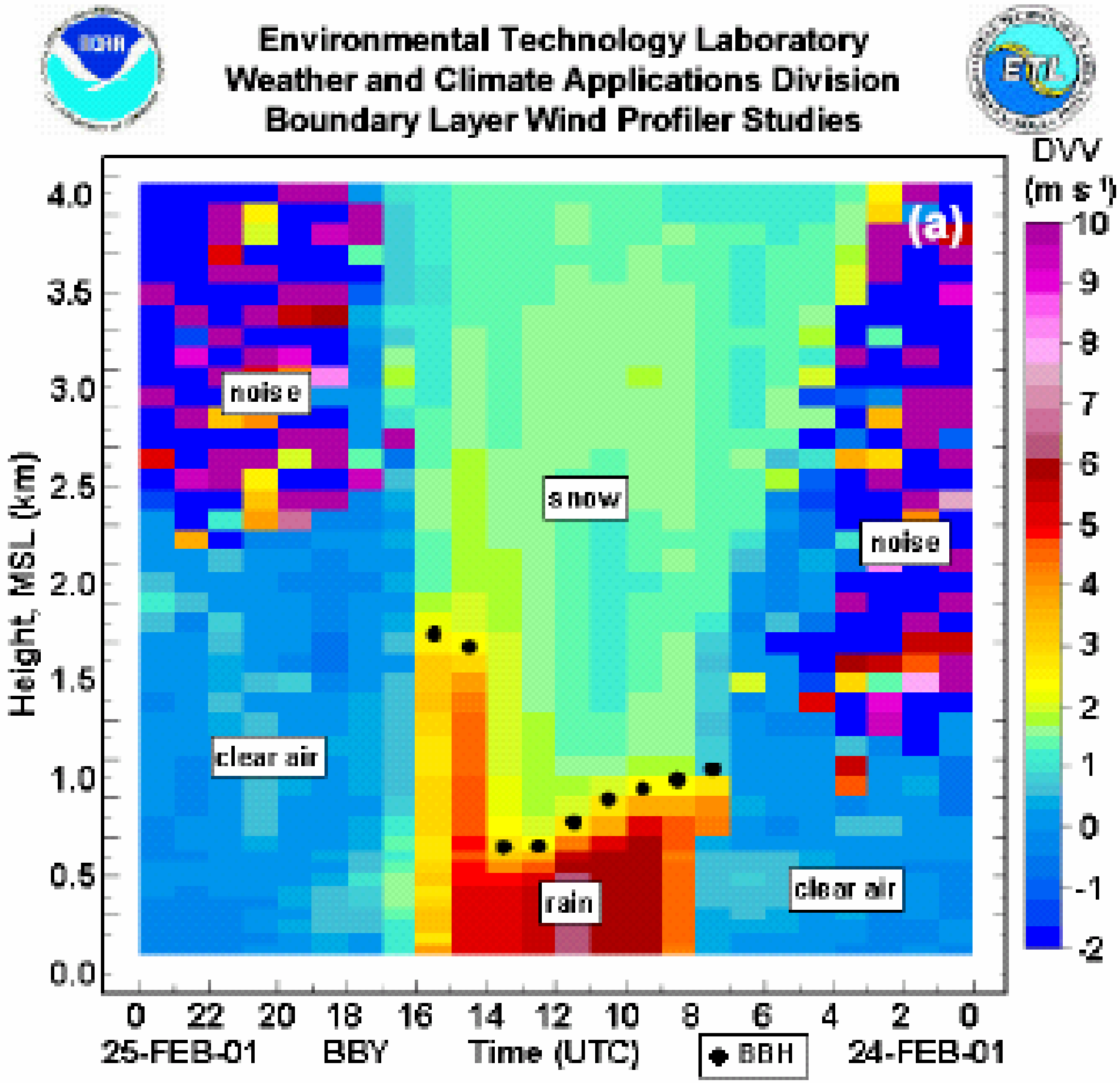
Juneau Alaska Turbulence Program



Advection from Hurricane Nora at Temecula, CA

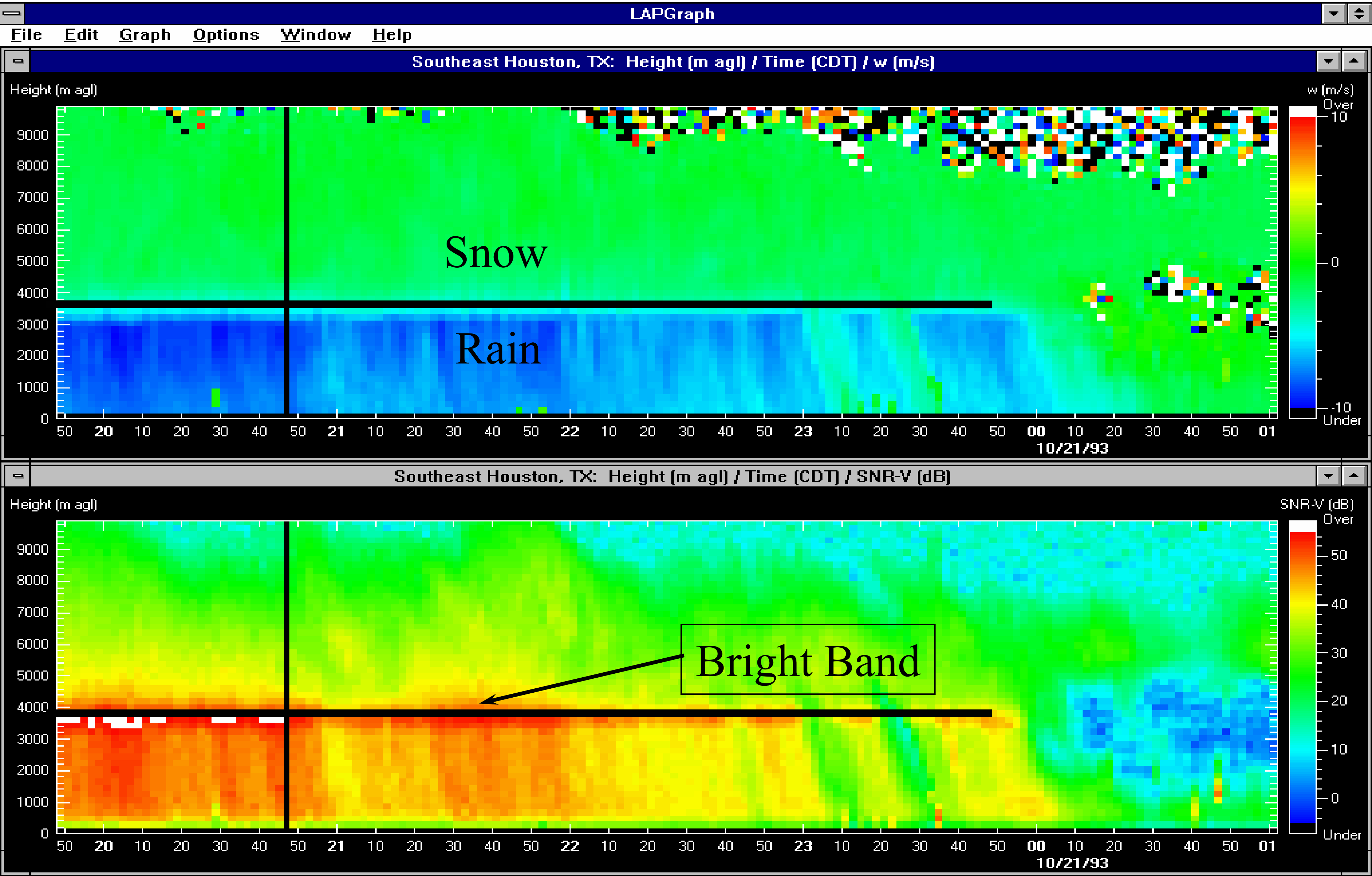


Rain/Snow based on Vertical Velocity

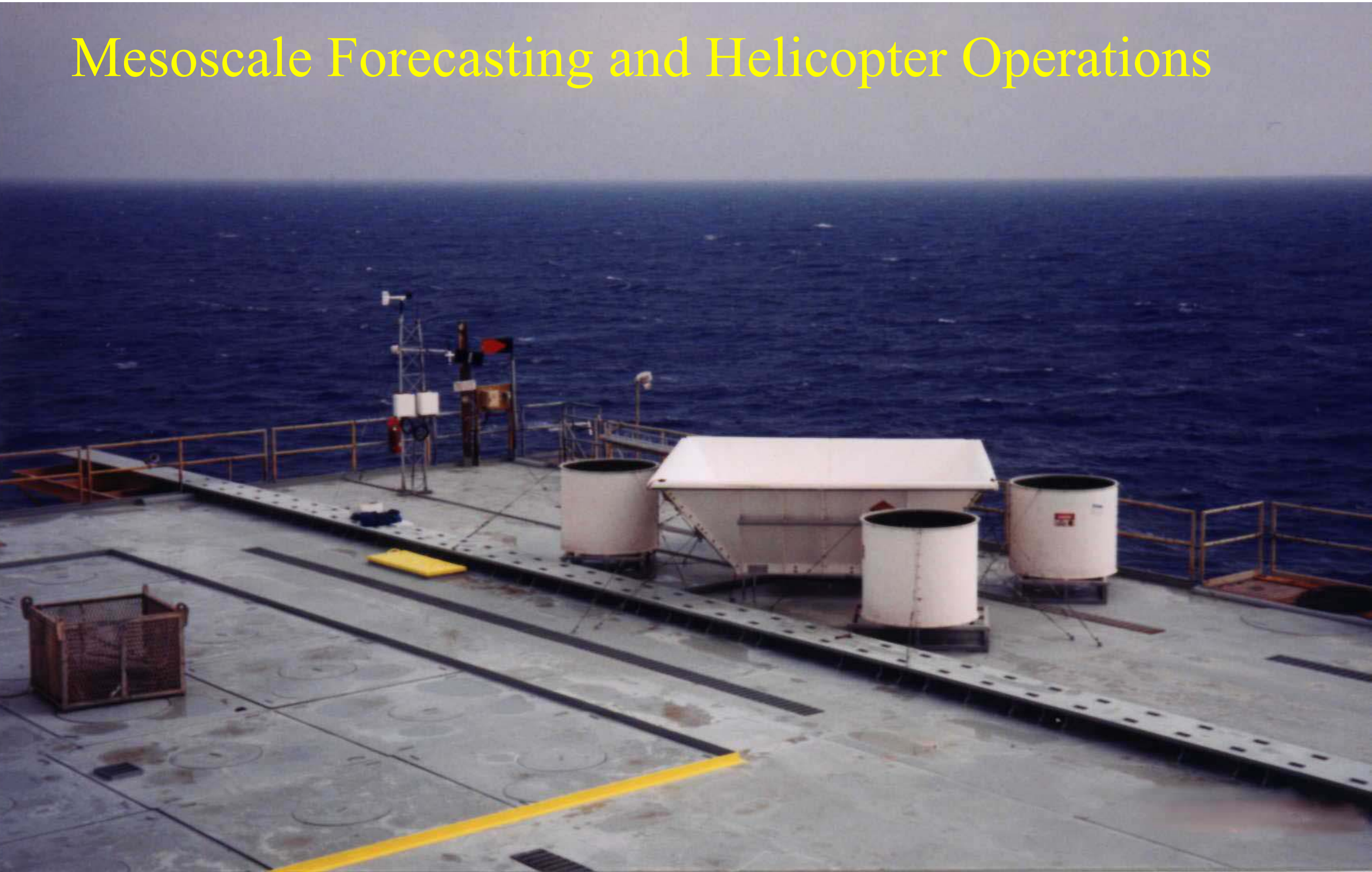


Courtesy of NOAA/ETL

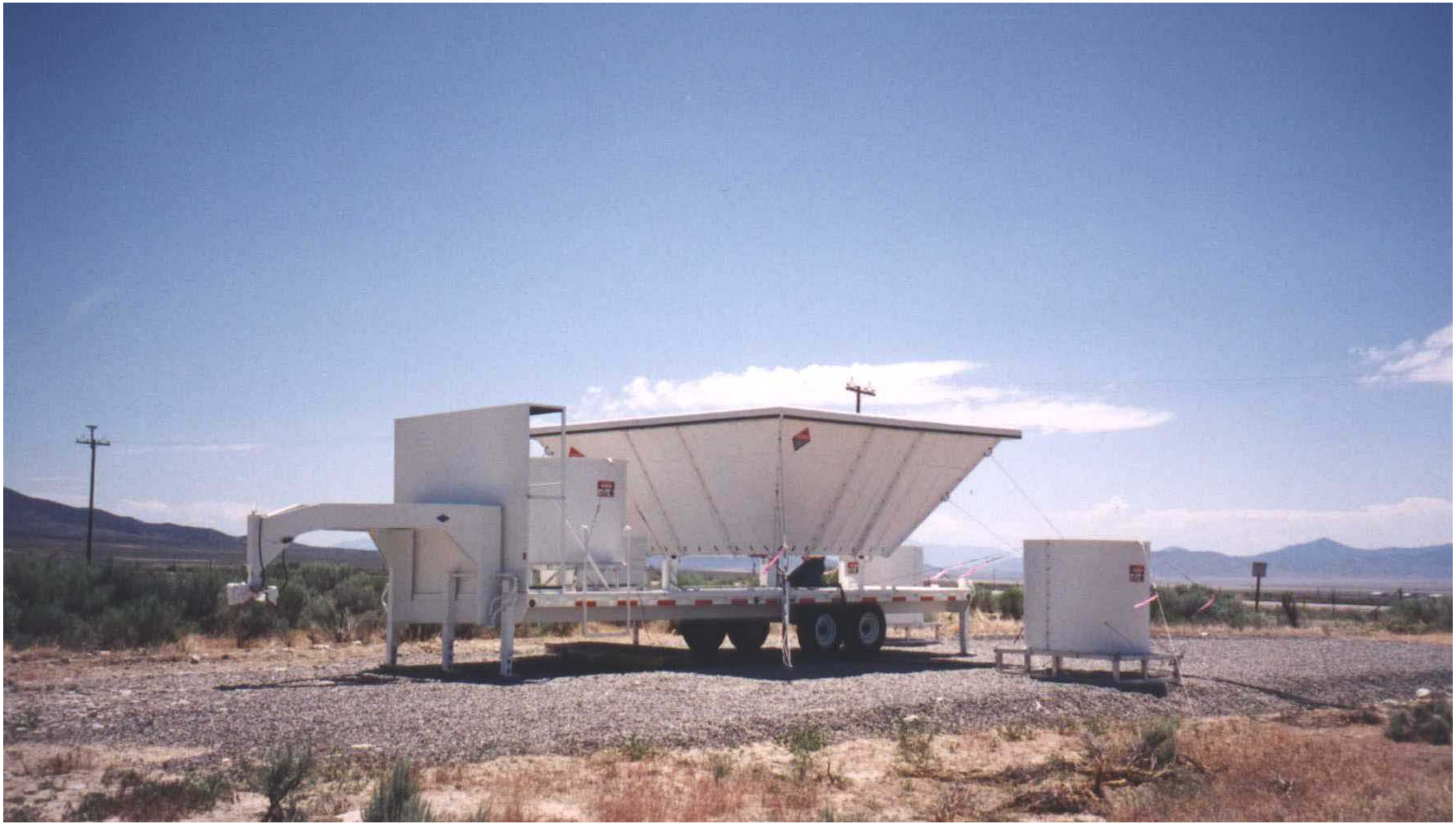
Freezing Level Detection



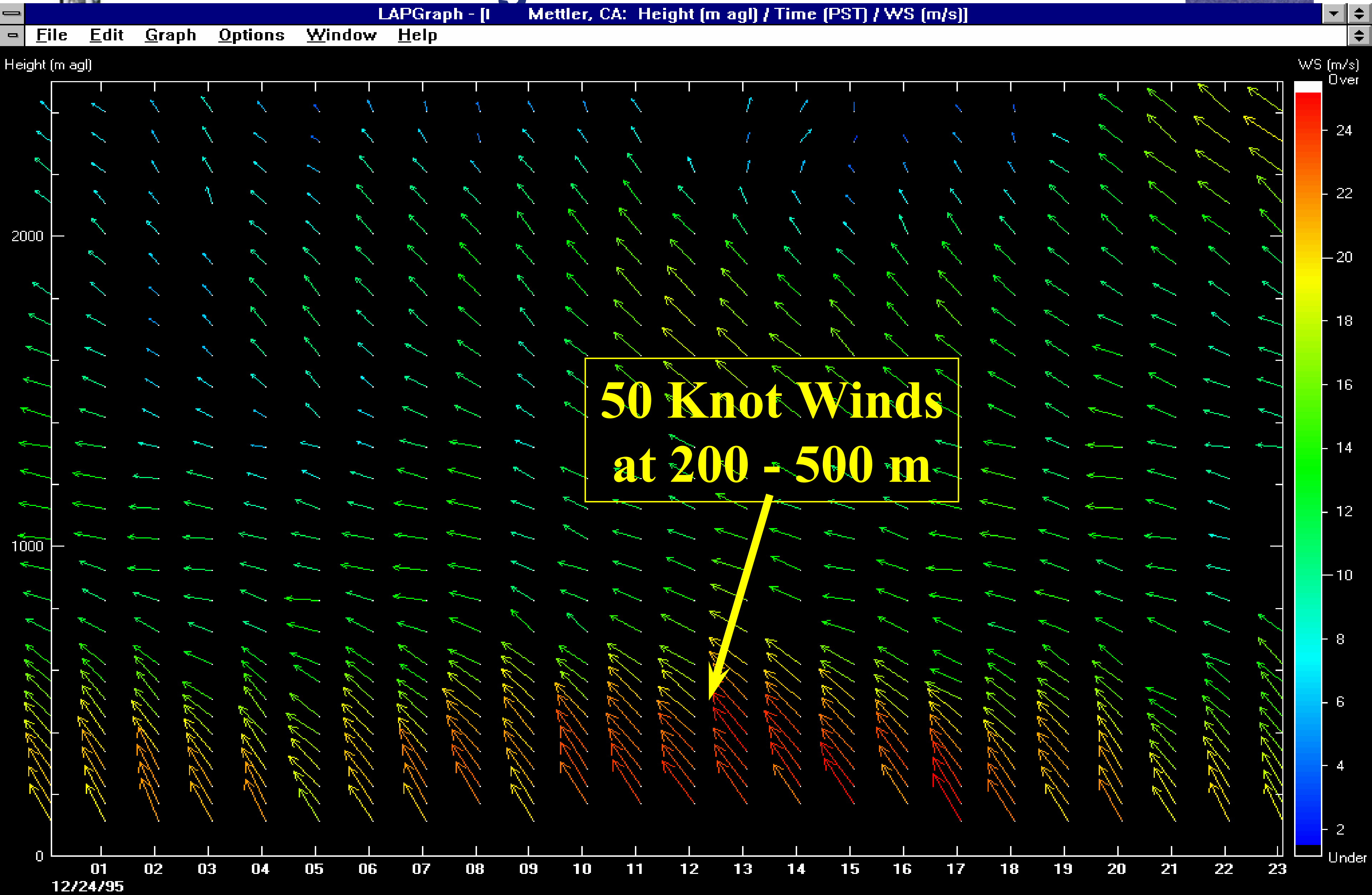
Boundary Layer WP in Gulf of Mexico, Offshore Oil Rig



Mobile Boundary Layer WP w/RASS



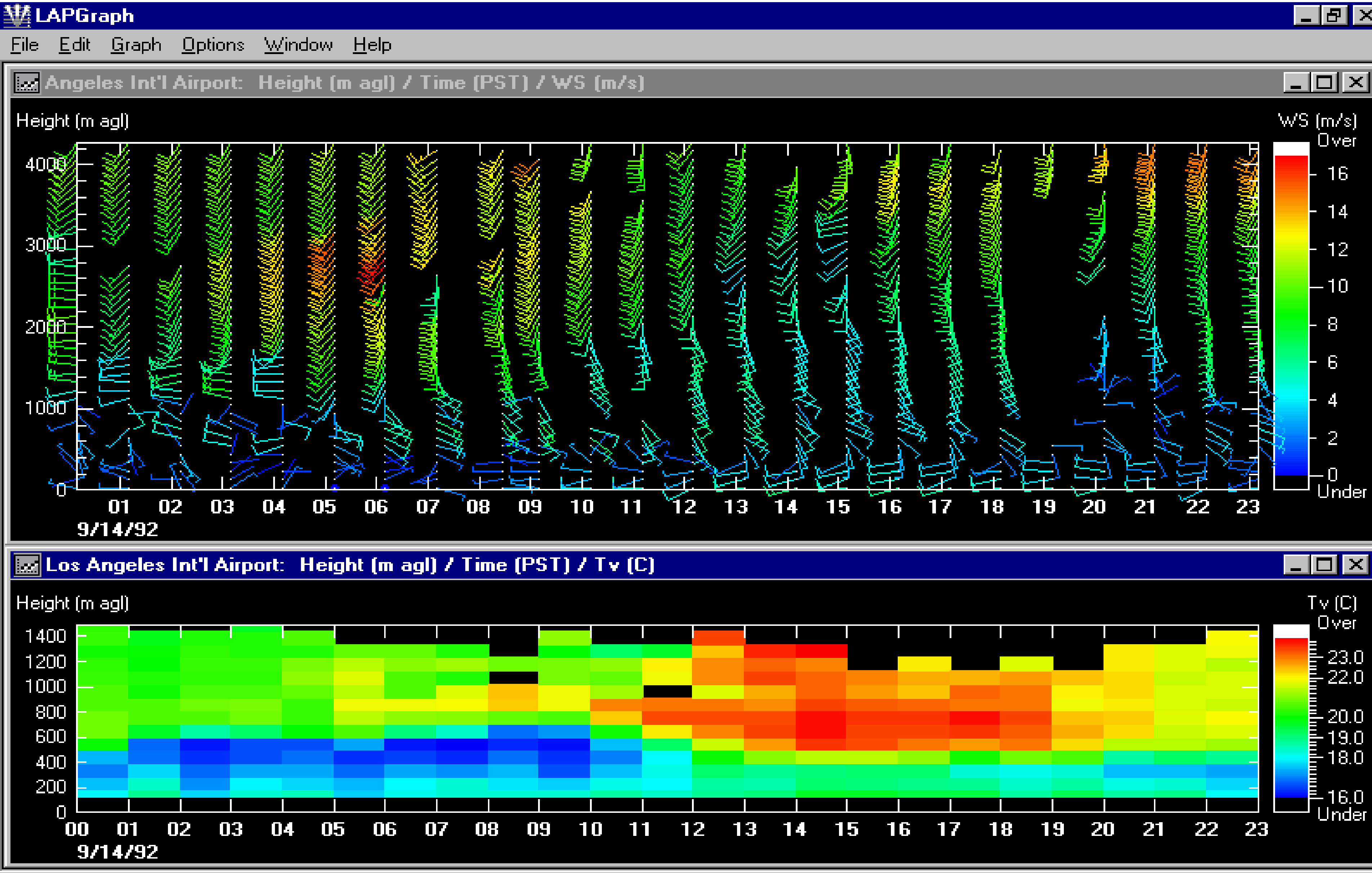
Strong Low-Level Winds



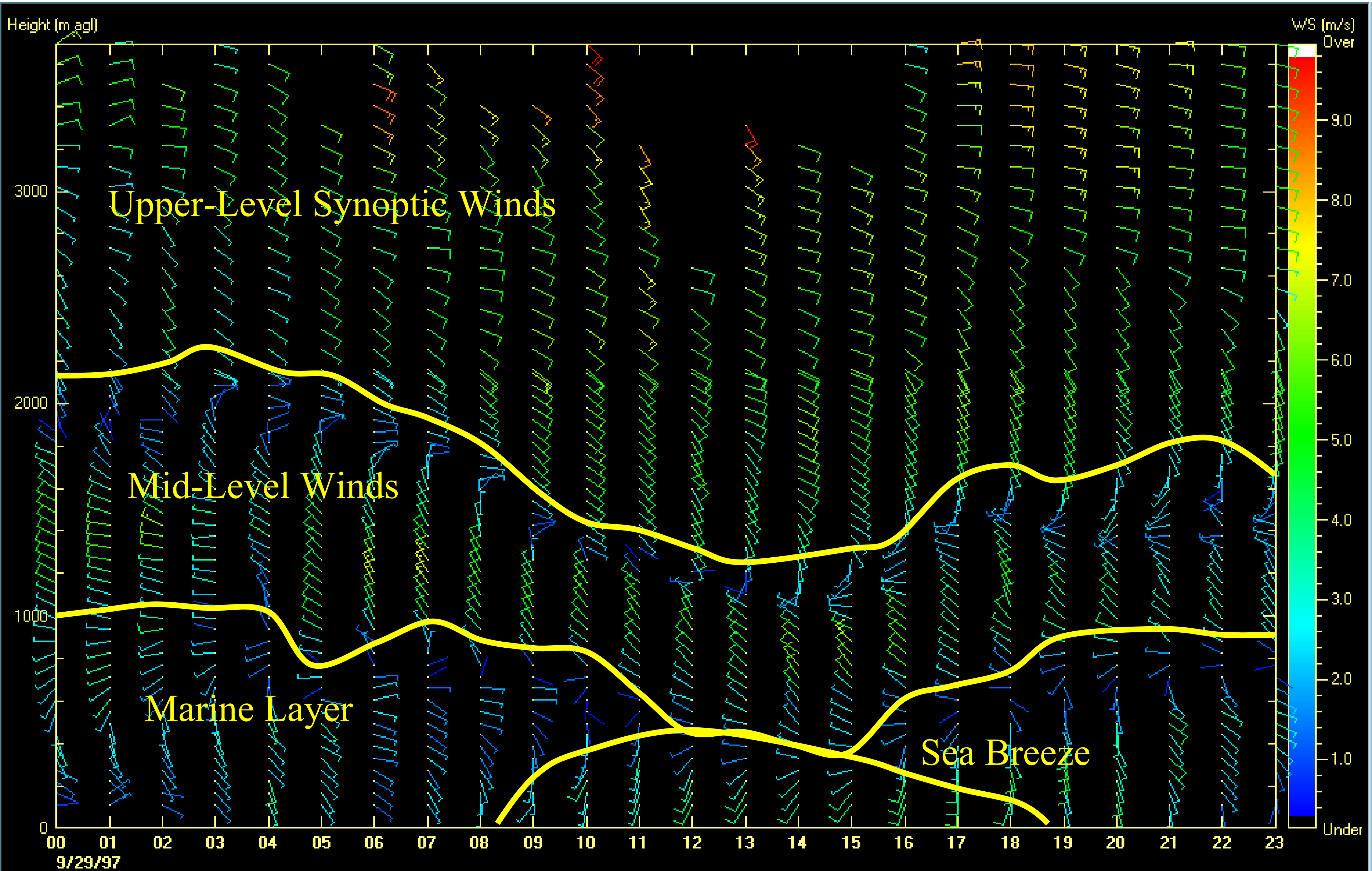
Mobile Military Prototype Boundary Layer WP

Boundary Layer WP at the foot of Mt. Etna, Catania, Sicily, Italy

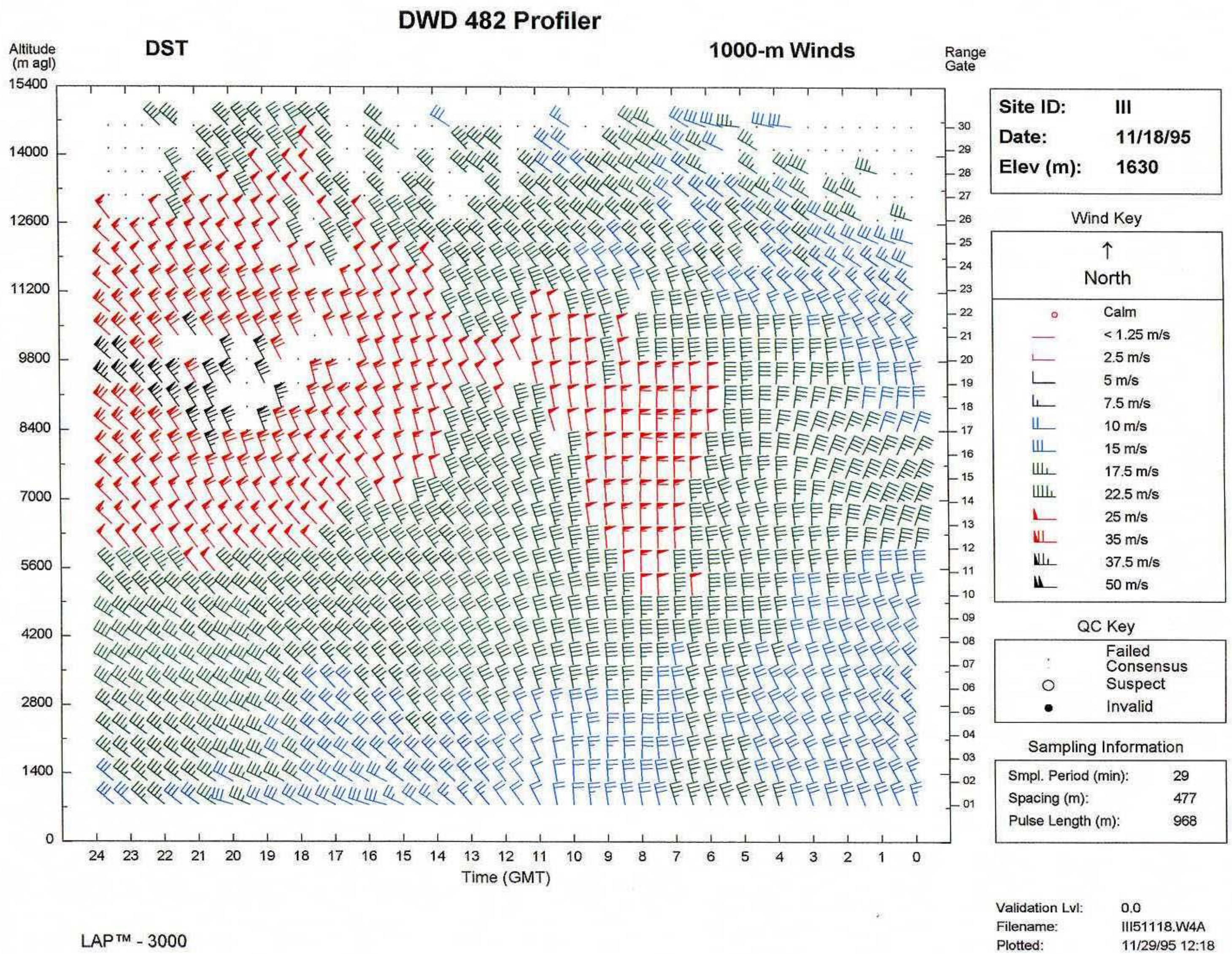
Sea Breeze at LAX



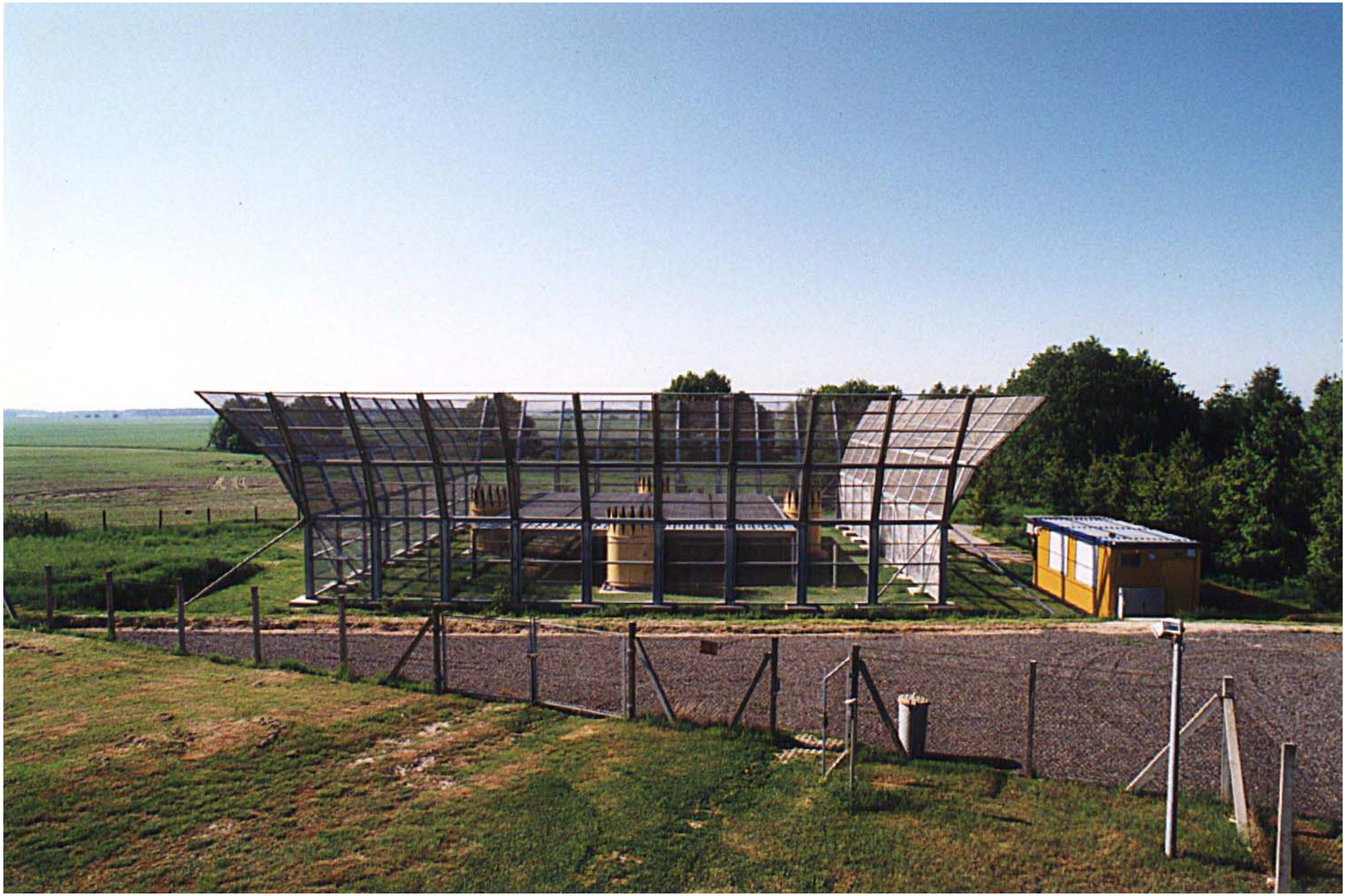
Multi-Level Shear Layers



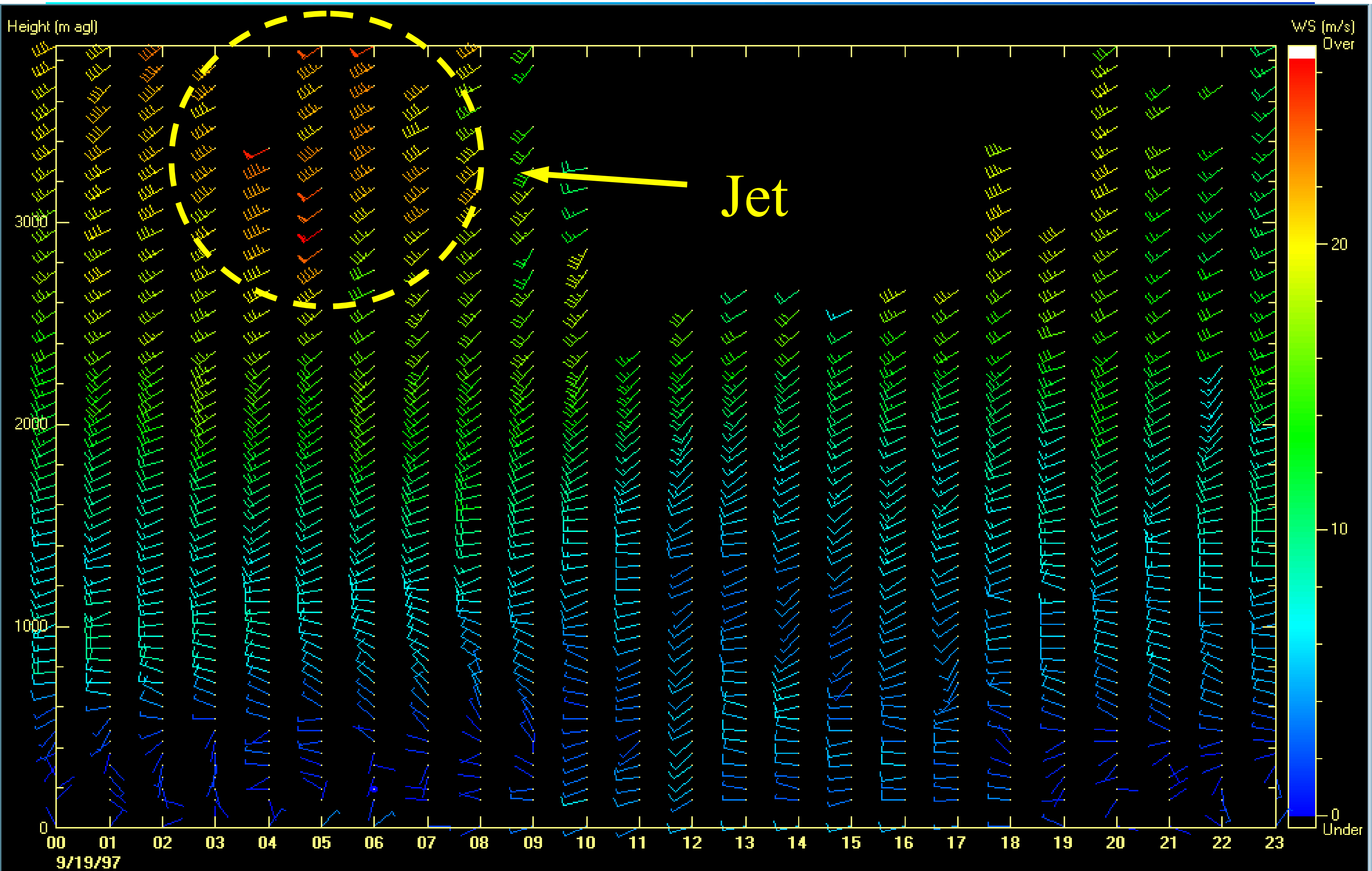
Tropospheric WP - Data



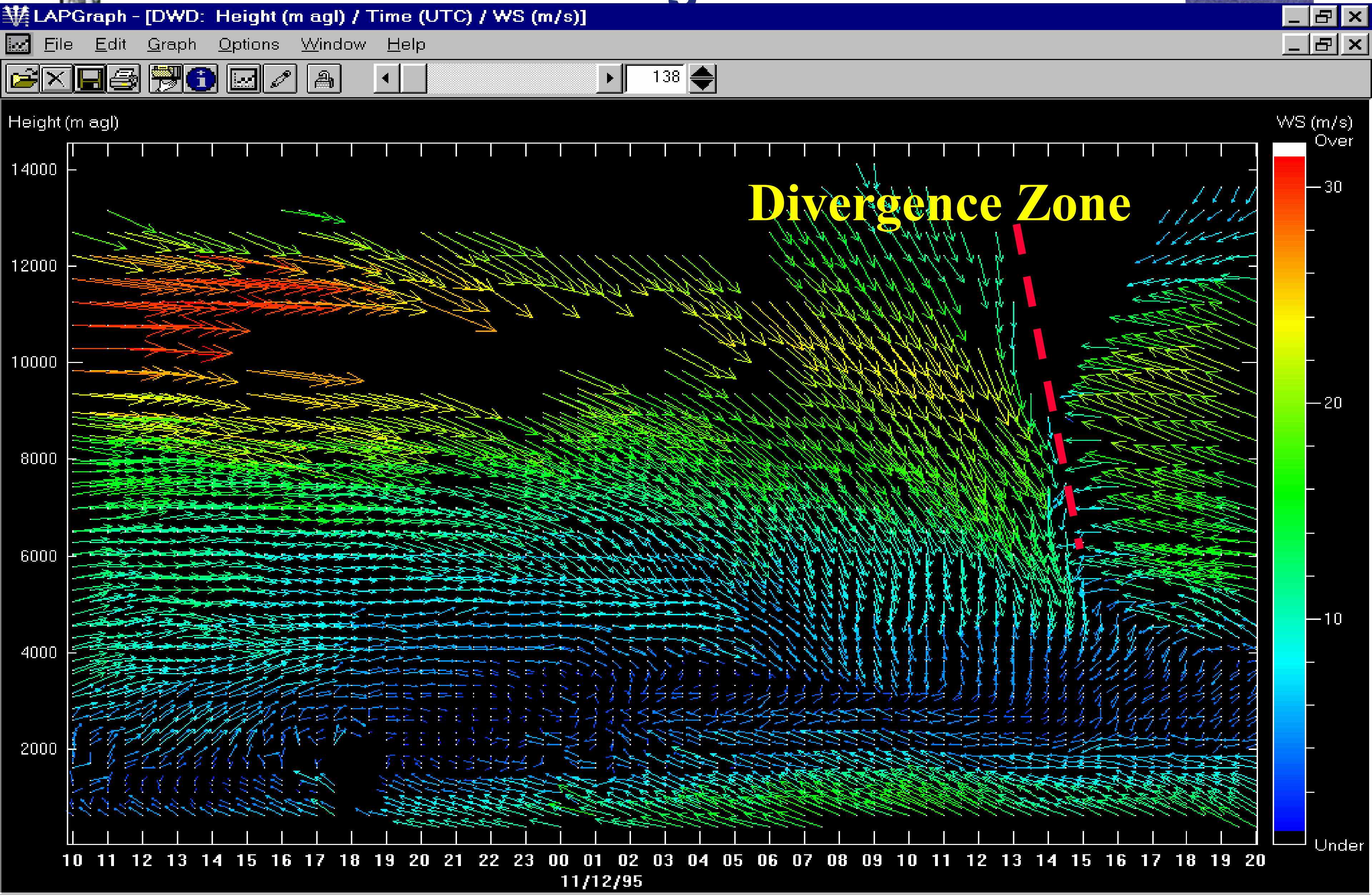
Tropospheric WP in Germany



Mid-Level Jet

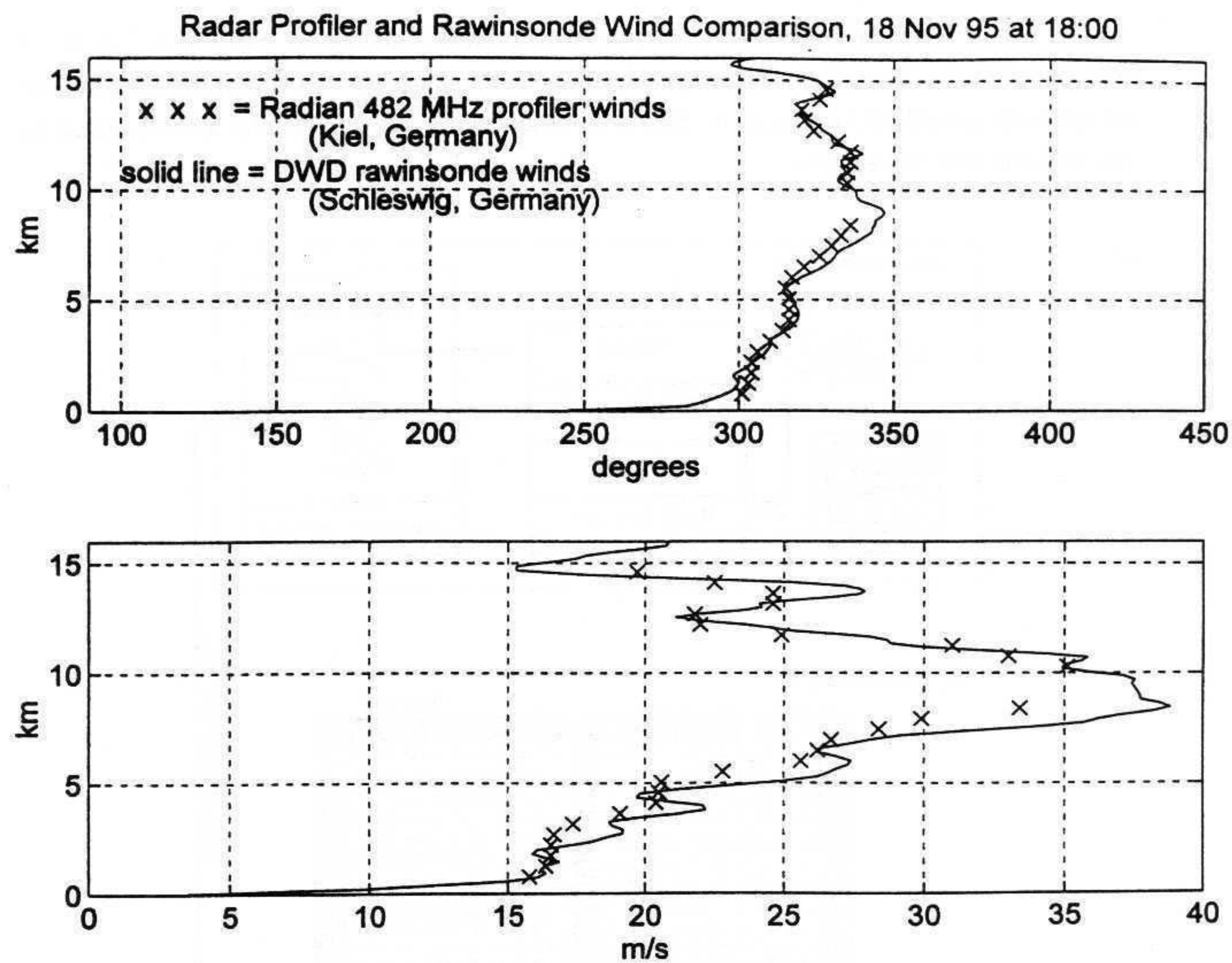


Aloft Divergence Zone

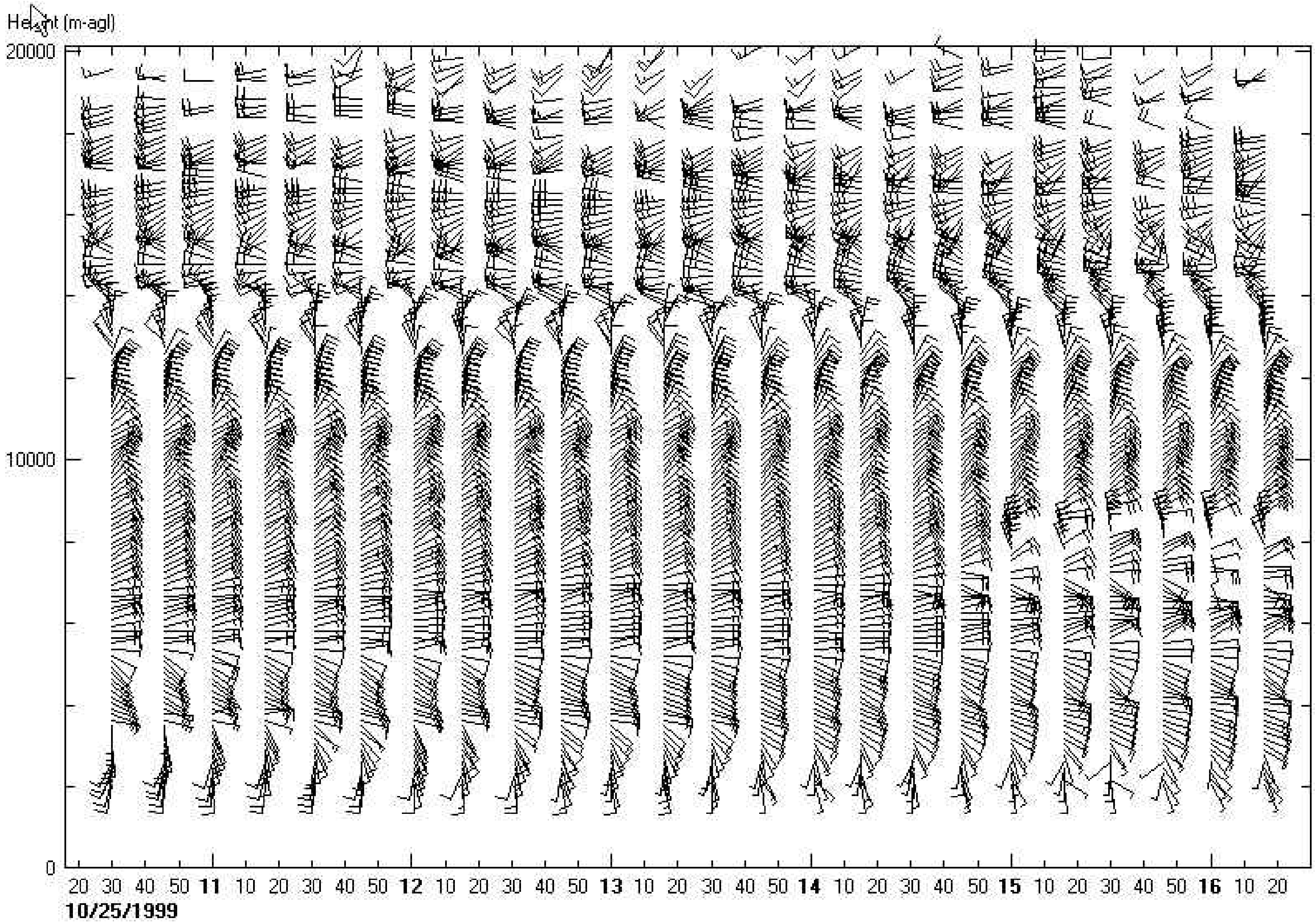


Boundary Layer WP at 924 MHz w/RASS (Foreground)
Tropospheric Radar Profiler at 50 MHz (Background)

Tropospheric WP - Data Verification



Time-Height Wind Data
From KSC 50 MHz Profiler



Selected Useful WEB pages

http://www.meto.gov.uk/research/interproj/cwinde/profiler/index.html

- The UK Met office coordination of European Wind Profilers

http://www.profiler.noaa.gov/jsp/index.jsp

- NOAA’s NPN and BLP Wind Profilers
- Observations on line from systems around the world

http://www.atd.ucar.edu/rtf/facilities/mapr/

- NCAR Activities